ONTARIO

DEPARTMENT OF LABOUR

MINISTER

THE HONOURABLE CHARLES DALEY

DEPUTY MINISTER

J. B. METZLER

COMBUSTION

OPERATING ENGINEERS BOARD

TORONTO
Printed by BAPTIST JOHNSTON, Printer to the King's Most Excellent Majesty
1948

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Parliament Buildings, East Block

PREFACE

From the time of Watt until about the end of the last century the attention of designing engineers was centred on perfecting the engine. Then they turned their attention to the turbine. During this period the boiler furnace was apparently overlooked and allowed to look after itself.

Within the last thirty years, however, attention has been directed to the boiler room with the result that revolutionary advancement in the manner of burning fuel is making rapid strides.

Much has been written in recent years on Combustion, but the information has only been accessible in works of an advanced character or in those which only profess to treat special branches of the subject. The present text-book is an attempt to give this information in a form suitable for beginners and easy to understand so that it can be followed by any engineer who possesses a slight acquaintance with the subject. There is nothing that can be termed original in the present work. The information which it contains has been freely drawn from books, magazines and catalogues. But it has been no easy task to deal with the various phases of Combustion and make the descriptions as simple as possible in the limits of space which this volume permits.

This book is the fifth of a series of text books on engineering subjects prepared by the Board and we trust it will meet with the encouraging response which has attended our previous efforts.

THE BOARD OF EXAMINERS,

OPERATING ENGINEERS,

East Block, Parliament Buildings,

Toronto.

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COMBUSTION

A THEORY OF THE ORIGIN OF COAL

The history of the world since its beginning is a very interesting study to those who are so inclined and this should include every person who engages in engineering.

For the first few millions of years man was not present to write books on this subject so nature wrote one herself. Each strata of rock is a leaf in nature's book and men are now finding the reading of this interesting book a fascinating study indeed.

The age of the world can only be conjectured, but it has been estimated that it is about 80 million years since the first hard crust formed upon its surface. It may be asked, how is it known? It is known by studying the thickness of the different layers of rock which have formed on its surface, and estimating the time required to form these different layers and by the change of position and wearing away in certain places. For instance, it is estimated that it has taken twelve thousand years for the waters of the Niagara River to cut the gorge from Lewiston to where the Falls now are.

In the early stage this earth was a molten mass so that no water was on it. All water existed in the air above in the form of steam or perhaps in the form of oxygen and hydrogen.

The carbon of which coal is principally composed, also existed in the air in the form of carbon dioxide (no incomplete combustion at that time). All sulphur also floated in the air in the form of sulphur dioxide, also chlorine and many other substances.

As the surface of the earth cooled, the surrounding atmosphere also cooled and in time the steam condensed and clouds were formed and it rained.

When it rained, water descended upon the earth, carrying down a part of the carbon dioxide, sulphur dioxide and other gases. It formed oceans of boiling water filled with acids, such as sulphuric acid, formed by the union of sulphur dioxide which was in the air when it rained.

Naturally the water from these boiling oceans evaporated rapidly and caused great downpours of rain which beat upon any surface exposed above the water, and wore away

the rock and washed it into the sea. Also the moon was closer to the earth in those days and caused tremendous tides to sweep over the earth and lash upon the rock, wearing it away and washing the loosened sediment into the bottom of the sea. The gases and acids held in suspension in the water united with the waste rock. The carbon dioxide united to form all the carbonates. The chlorine united to form chlorates and chlorides. This is where our common table salt came from.

The sediment sank to the bottom of the ocean and formed a layer over the original rock and the first page of the history of the world was written.

As the world cooled, the waters of the oceans no longer boiled although still warm. The sediment ground down from the rocks formed soil on the shores. The climate was hot and the air was laden with moisture and carbon dioxide. It was hot sultry weather but good growing weather.

About this time life for the first time appeared upon the earth in the form of vegetation. It can be understood by us how life multiplied, or at any rate we see it multiply, but how it first originated we cannot conceive. Our finite brains are unable to think in the infinite. The origin of life will remain a mystery until we solve what life really is and this can never be accomplished with our finite minds.

At any rate, life appeared in the form of trees and the climate was suited for rapid growth. Lots of moisture and plenty of food for the roots and plenty of carbon dioxide in the air for the leaves to absorb. Practically the whole continent was one vast swamp. Great trees lived, grew and fell in the muck, not to rot but to be preserved. Other great trees grew and fell until thick layers of what we now call "black muck" or "peat" was formed.

But during all this time the surface of the earth was not peaceful. The shell was thin and as cooling took place it caused contraction. This caused the shell to crack and great ridges to be heaved high in the air while other sections sank. Where forest once flourished, ocean would be formed and the remains of the trees buried beneath it. As time went on the sediment washed down from the hills by the new rivers would form a thick layer over the peat and this sediment in time would turn to rock and imprison the peat beneath it.

Under great pressure for countless ages the peat was transformed to coal as we find it in the mine today.

Sometimes the surface of the earth would again change and the sunken portion would be forced up again. Vegetation again would spring up and another layer of peat formed, after which it was again sunk and a new layer of coal formed. As many as one hundred seams of coal have been found in one mine.

Practically all America was once lined with seams of coal, but unfortunately, sometimes when great upheavals took place the coal was exposed and the storms beating upon it for ages, washed all the coal away to the sea.

Sad to say, this is only too true in our own Province of Ontario, and we today are suffering from a disaster that took place many thousands of years ago.

Spontaneous Combustion of Coal (U.S. Bureau of Mines)

Spontaneous combustion is brought about by slow oxidation in an air supply sufficient to support the oxidation, but insufficient to carry away all the heat formed. Mixed lump and fine, that is, run-of-mine, with a large percentage of dust, and piled so as to admit to the interior a limited supply of air, make ideal conditions for spontaneous heating. High volatile matter does not of itself increase the liability to spontaneous heating.

Freshly mined coal and even fresh surfaces exposed by crushing lump coal exhibit a remarkable avidity for oxygen, but after a time become coated with oxidized material, "seasoned", as it were, so that the action of the air becomes much less vigorous. It is found that if coal which has been stored for six weeks or two months and has even become already somewhat heated, be rehandled and thoroughly cooled by the air, spontaneous heating rarely begins again.

While the following recommendations may under certain conditions be found impracticable, they are offered as being advisable precautions for safety in storing coal whenever their use does not involve an unreasonable expense.

1. Do not pile over 12 feet deep nor so that any point in the interior will be over 10 feet from an air-cooled surface.
2. If possible, store only in lump.
3. Keep dust out as much as possible; therefore reduce handling to a minimum.
4. Pile so that lump and fine are distributed as evenly as possible; not, as is often done, allowing lumps to roll down from a peak and form air passages at the bottom.
5. Rehandle and screen after two months.
6. Keep away external sources of heat even though moderate in degree.
7. Allow six weeks' "seasoning" after mining before storing.
8. Avoid alternate wetting and drying.
9. Avoid admission of air to interior of pile, through interstices around foreign objects such as timbers or irregular brick work; also through porous bottoms such as coarse cinders.
10. Do not try to ventilate by pipes, as more harm is often done than good.

Combustion

Dry coal is composed of nitrogen, oxygen, carbon, ash, sulphur and hydrogen. It will assist the reader to remember these substances if he keeps in mind the two words "no cash". It will be noticed that each letter in these words is the first letter of one of the constituents of coal.

It must not be thought, however, that coal is just so many parts of each of these constituents packed together into one piece of coal. It is true a certain amount of carbon does exist in the coal by itself and is known as fixed or free carbon. But, another part of the

carbon is in chemical composition with the gases in the form of hydro-carbons. These hydro-carbons are combinations of carbon and hydrogen in many different proportions. Their chemical symbols being CH_2, $C_2 H_4$ and many other more complex combinations, and are known as olefiant gas, pitch, tar, naptha and others, some of which are a combination of carbon, hydrogen and oxygen.

A certain amount of free hydrogen, nitrogen and oxygen are present also, as well as a combination of hydrogen and oxygen in the form of water. There are also small percentages of sulphur and a quantity of ash, varying from 3 to 30 per cent. Ash has no heating value and interferes with efficient combustion by hindering free air passage. Sulphur is an undesirable quantity as it has a low heating value and when burned forms SO_2 and SO_3 which when mixed with water forms sulphurous and sulphuric acid. It also unites with the ash forming fusible clinkers and if present in any considerable quantity will give serious trouble in this respect.

Some moisture is always found in coal. This causes a direct loss as this water is turned to steam and in superheating this steam to the temperature of the furnace gases no benefit is derived from it. Some coal appears to give better results when a certain amount of moisture is present, but this is apparently due to the steam loosening and breaking up the coal.

When heat is first applied to coal the volatile matter separates from the coal and if mixed with hot air complete combustion will take place, that is, all the matter with the exception of the nitrogen and ash will unite with the oxygen of the air, or in other words, it will all be burnt. The carbon will unite with oxygen, forming carbon dioxide and the hydrogen will unite with oxygen, forming water.

When the fixed carbon burns it unites with oxygen, forming carbon dioxide. Any sulphur present will also burn, forming sulphur dioxide. All these gases together with the nitrogen of the air from which the oxygen has been burned, will pass through the flues of the boiler and up the stack. All the coal passes off in the form of gas except the ash which is left on the grates.

If the volatile gases are mixed with cold air they are liable to become chilled and pass off unburnt. Should they be brought to a red heat before coming in contact with air of sufficient quantity they tend to break up, disengaging the carbon in small particles. Should this carbon be chilled below the point of ignition before coming in contact with air, it will pass off in the form of smoke, or, if it came in contact with a solid body it will settle as soot. This invariably happens when the grates are placed too close to boiler shell. Should it come in contact with sufficient air and be of sufficient temperature for ignition, it will burn and no black smoke will issue from the smoke stack.

Carbon unites with oxygen in the proportion of one atom of carbon to two atoms of oxygen, providing sufficient oxygen is present, the chemical formula being $C + O_2 = CO_2$.

The atomic weight of carbon is 12 and that of oxygen 16, therefore 12 pounds of carbon require 32 pounds of oxygen to form complete combustion. Carbon will also unite with oxygen in the proportion of one atom of carbon to one atom of oxygen. The formula

being $2C + O_2 = 2CO$. This combination takes place only when there is not sufficient oxygen present to form CO_2. This is known as incomplete combustion.

One pound of carbon burned to CO_2 (carbon dioxide) will produce 14,500 B.T.U.'s of heat. The importance of having sufficient air enter the furnace can be easily seen there-heat, but when burned to CO (carbon monoxide) it will only produce 4,400 B.T.U.'s of fore, as less than one-third of the heat is produced in burning carbon to CO rather than to CO_2.

Weight of Coal

While coal has a specific gravity between 1 and 2, and a solid cubic foot would weigh over 80 pounds, the weights of broken coal as mined and shipped range from 44 to 54 pounds per cubic foot, and in some cases, with anthracite, up to 58 pounds.

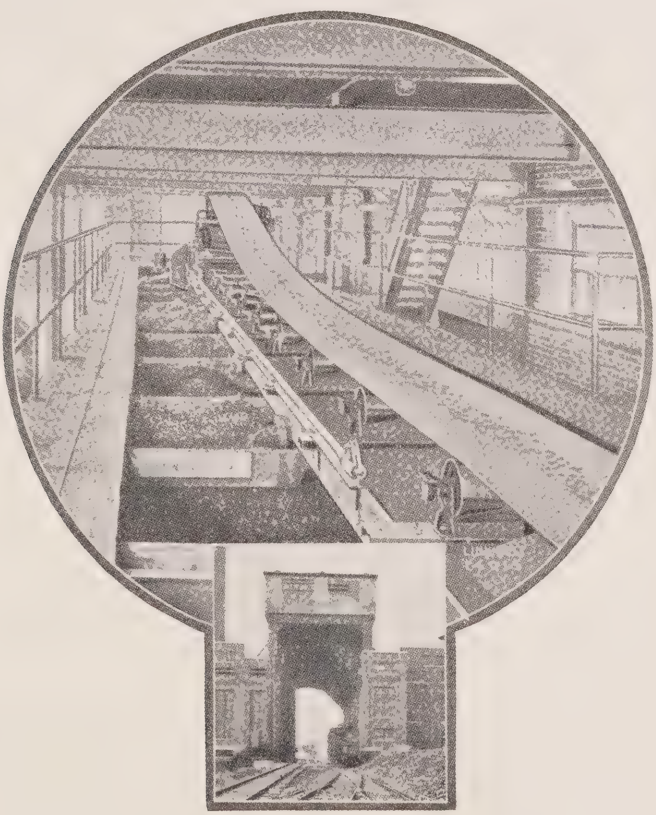

FIG. 1. Belt Coal Conveyor.

Weighing Coal

In order that a check can be kept on the amount of coal burned some sort of weighing device should be installed in every power plant.

There are a great many devices on the market for this purpose. In small plants where the coal is wheeled into the boiler room, each barrowful is weighed on ordinary scales.

In plants using an overhead bunker and a travelling hopper beneath for distributing the coal to each boiler, the travelling hopper is fitted with scales by which the coal can be weighed each time the hopper is filled.

Some power plants are equipped with a separate weighing machine for each boiler. The coal is fed into the hopper from a bunker mounted on scales, where it is weighed. It is then fed down through a spout to the furnace.

Large plants are equipped with weigh scales of sufficient capacity to weigh a car load at a time when it is delivered to the plant and before being conveyed to the storage pile.

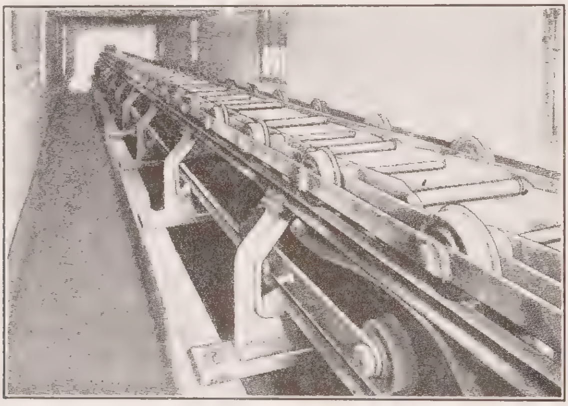

FIG. 2. Bucket Conveyor

Coal Conveyors

In large plants where coal is delivered by rail, the usual method of handling the coal is to run the car over a hopper and dump it. The coal is then fed from the hopper down into a coal crusher. As it is crushed it falls onto a conveyor and is carried to the bunker in the boiler room which is placed high enough for the coal to be fed by gravity to the furnaces.

Fig. 1 shows a belt conveyor. It consists of a wide endless rubber belt running on cone shaped pulleys which keep the centre of the belt lower than the outer edges. As the coal is fed from the car through the crusher it falls on the belt and is conveyed to the overhead bunker.

Fig. 2 shows another type of conveyor. It consists of a travelling endless chain, the links of which are pivoted bucket carriers. As in the case of the rubber belt, the coal falls into the buckets and is carried to the overhead bunkers.

Fig. 4 shows a number of different methods of handling storage coal.

Coal Crusher

When "run of mine" coal is received in the boiler plant it is composed of lumps of many various sizes. Large lumps are not satisfactory for firing particularly when stokers are used. Crushers are generally installed beneath the receiving coal hoppers.

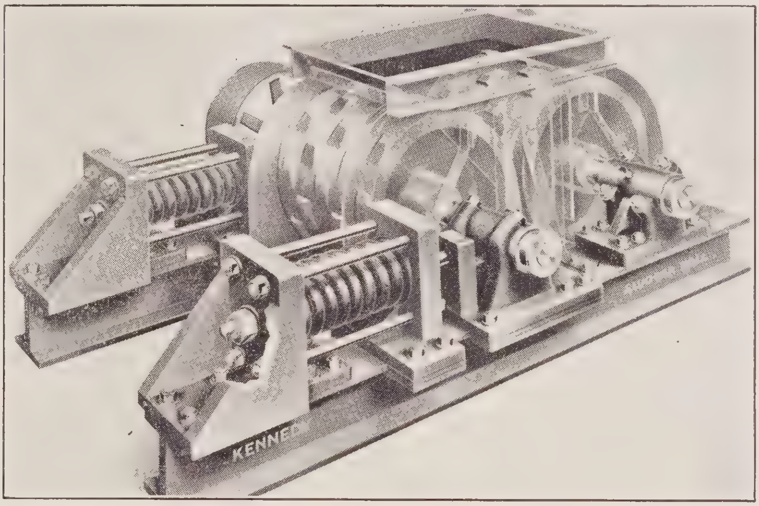

Fig. 3. Coal Crusher

Ash Handling Systems

The ash handling system with which the majority of us are most familiar is the wheel barrow. When the ashes have been pulled out the firedoor and are cooled, they are loaded into the barrow and wheeled away to the outside.

In modern plants where there is sufficient head room for a basement under the boilers, hoppers are built to receive the ashes as they are dropped from the grates. When a quantity of ash accumulates in the hopper, the hopper is emptied into a dump car and the ash taken away.

In plants where there is no basement the ash must be pulled out on to the boiler room floor.

Of the various devices, aside from the wheel barrow, which have been conceived for conveying ash, the conveyor shown in Fig. 2 is frequently used. When in use it operates in a trough in the floor in front of the boiler and carries the ash up the side of a wall to deposit it in a suitable bin. This bin is sufficiently high that a car can go under to receive the ash which is dumped into it.

Pneumatic Ash Conveyors

These consist primarily of a pipe through which a current of rapidly moving air carries the ashes to any desired point. Inlets to receive the ashes consist of tees which are plugged when not in use; and are provided wherever convenient, such as in front of the ashpits. The

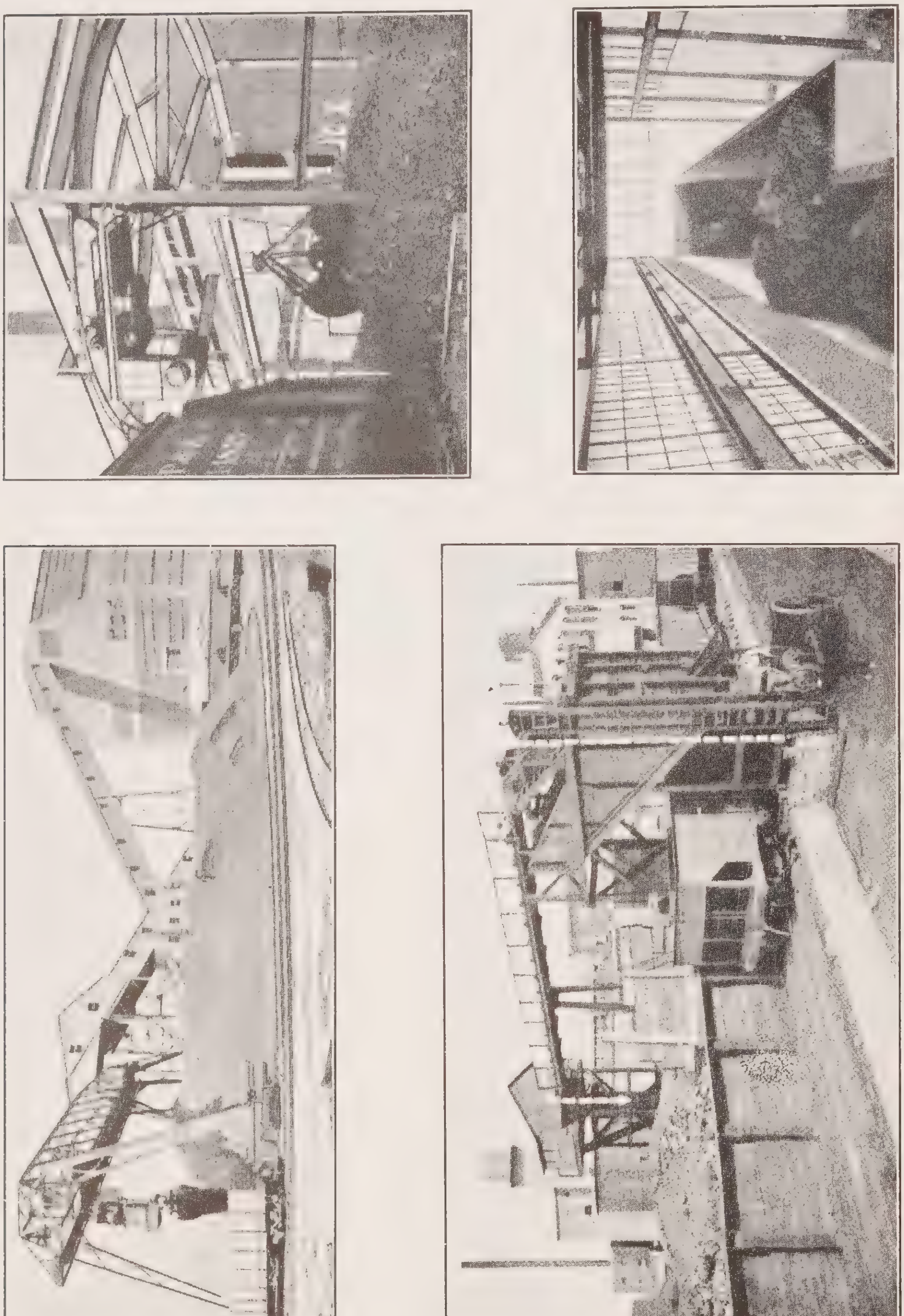

FIG. 4. Different methods of handling coal.

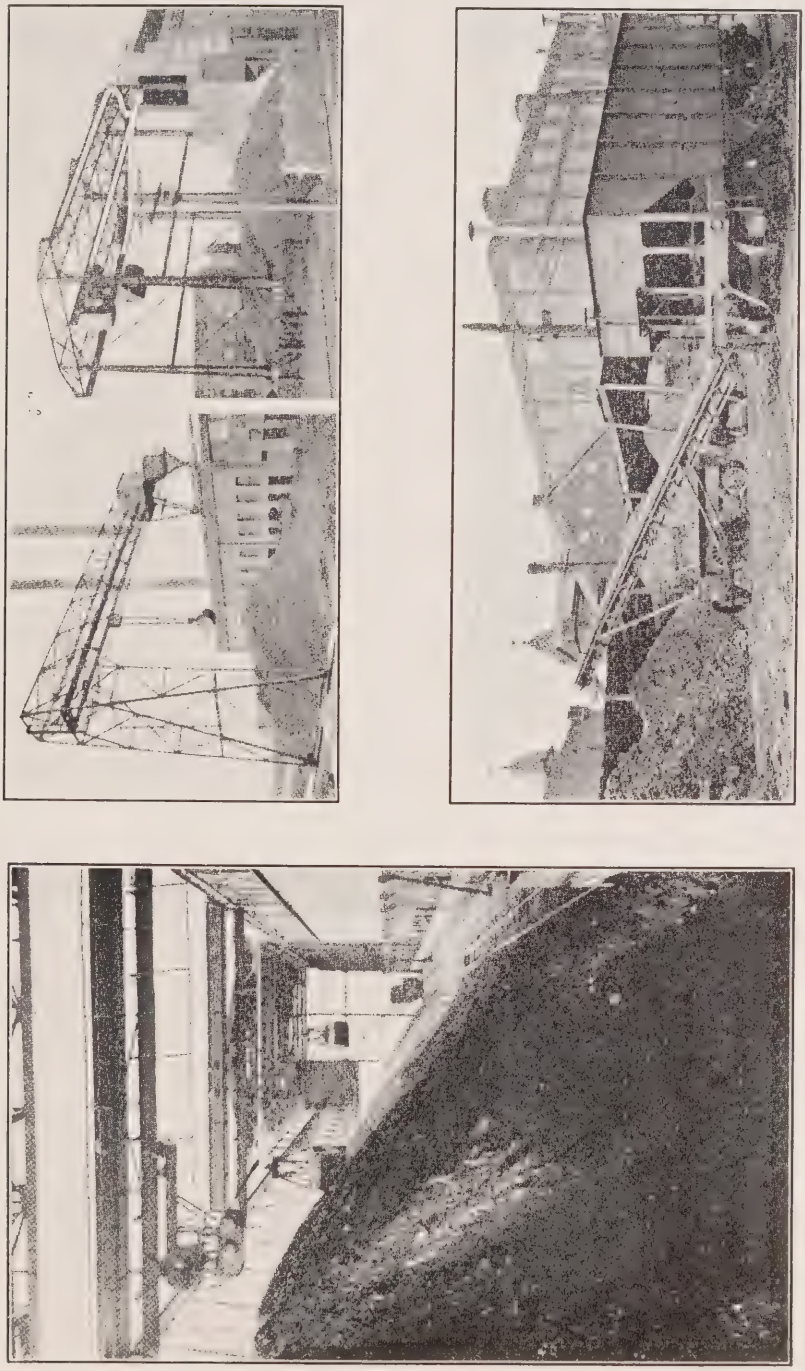

FIG. 4a. Different methods of Handling Coal.

conveyor may discharge onto the ground or into a hopper from which cars and wagons may be filled. The commencement of the pipe should have an open end, so that there is an ample flow of air along the pipe at the first ash inlet.

In vacuum conveyors, a vacuum is produced in a closed tank, either by means of a motor-driven or a steam jet exhauster. When steam-jets are used, they may either be arranged to exhaust from a hopper as just described, or may be introduced at some point or points after the last inlet, generally at a bend in the conveyor pipe. Steam-jet conveyors may either discharge into the open or into vented tanks.

Heating Value of Coal Obtained by Ultimate Analysis

As coals vary greatly in the amount of moisture, fixed carbon, volatile matter and ash, the purchaser should buy coal by its heating value, that is, the number of B.T.U.'s it contains rather than by the number of tons.

The heating value of coal can be obtained by the use of a calorimeter.

Kent describes the calorimeter as follows:

"Mahler's calorimeter apparatus consists of a strong vessel or "bomb" immersed in water, proper precaution being taken to prevent radiation. One gram of the coal to be tested is placed in a platinum boat within this bomb, oxygen gas is introduced under a pressure of 20 to 25 atmospheres and the coal ignited explosively by an electric spark. Combustion is complete and instantaneous, the heat is radiated into the surrounding water, weighing 2,200 grams, and its quantity is determined by the rise in the temperature of this water, due corrections being made for the heat capacity of the apparatus itself. The accuracy of the apparatus is remarkable, duplicate tests giving results varying only about 2 parts in 1,000.

The close agreement of the results of calorimetric tests when properly conducted, and of the heating power calculated from chemical analysis, indicates that either the chemical or the calorimetric method may be accepted as correct enough for all practical purposes for determining the total heating power of coal. The results obtained by either method may be taken as a standard by which the results of a boiler test are to be compared, and the difference between the total heating power and the result of the boiler test is a measure of the inefficiency of the boiler under the conditions of any particular test."

The theoretical value also may be determined by first obtaining chemical analysis.

This, of course, can only be done by an analytic chemist. Having obtained an analysis, "Dulong's" approximate formula is generally used, which is:

$$H = 145\ (C + 4.28\ (H - \frac{0}{8}) + .28S)$$

For instance, if the analysis of a certain coal was:

C = Carbon	=	88.26	per cent
H = Hydrogen	=	4.66	" "
N = Nitrogen	=	1.85	" "
S = Sulphur	=	1.77	" "
Ash	=	3.66	" "
		100.00	per cent

Substituting in the formula we have:

$$H = 145\left(88.26 + 4.28\left(4.66 - \frac{0.6}{8}\right) + 0.28 \times 1.77\right) = 15715 \text{ B.T.U.'s}$$

To make use of this formula a chemical analysis must be made of the coal, that is, the coal must be reduced to the original elements of which it is composed and the percentage of each obtained. This is called the Ultimate Analysis and can only be made by an experienced chemist.

Heating Value of Coal by Proximate Analysis

Another method known as the Proximate Analysis is much more commonly used and is much easier to make. It consists of dividing the coal into its percentage of moisture, fixed carbon, volatile matter and ash.

A Proximate Analysis is accomplished by taking a known quantity by weight of pulverized coal and treating it as follows:—

To Obtain Percentage of Moisture

Place the coal in a porcelain crucible and heat to a temperature of 212. Keep this temperature for a course of an hour or so, until all moisture is driven off. Then weigh the coal and the difference of weight of the dry and the original coal will be the amount of moisture.

To Obtain the Percentage of Volatile Matter

After the moisture is driven off and dry coal weighed, the crucible is held over a hot flame until all volatile matter is driven off, leaving only the fixed carbon and ash. The remaining carbon and ash is then weighed and their weight subtracted from the weight of dry coal will give the weight of volatile matter.

To Obtain the Weight of Fixed Carbon

That which is left after the volatile matter is driven off is burnt and nothing will now be left but the ash. The ash is then weighed and its weight subtracted from the weight of carbon and ash before burning. This gives the weight of carbon.

Knowing the weight of the original coal and the weight of each of the constituents, it is easy to calculate the percentage of each. For instance, the percentage of ash will be:

$$\frac{\text{Wt. of Ash}}{\text{Wt. of Coal}} \times 100 = \text{percentage of ash.}$$

The heat value of coal can be determined with a fair degree of accuracy from the proximate analysis. This is done as follows:

In the following formula let

$H =$ heat per lb. of coal in B.T.U.'s.
$C =$ percentage of fixed carbon
$A =$ a constant taken from the following table
$V =$ percentage of volatile

$$\text{Then } H = \frac{14670C + (A \times V)}{100} \text{ B.T.U.'s}$$

$V = 2$ to 15	$A = 20000$
$V = 15$ to 30	$A = 16000$
$V = 30$ to 35	$A = 10000$

Example: From the sample of coal just analysed determine the heat value.

Analysis:	Moisture	Volatile	Fixed Carbon	Ash
	12.90	16.80	62.00	8.30

$$H = \frac{14670 \times 62.00 + 16000 \times 16.80}{100}$$

$$= \frac{910000 + 269000}{100}$$

$$= 11790 \text{ B.T.U.'s}$$

Preparation of Sample of Coal for Analysis

In preparing a sample of coal to be sent to a chemist for analysis, care should be taken that it represents the average heating value of the whole quantity. Never pick out just a few lumps of the best looking coal. The only true method of obtaining the real heating value of the total is to include the worst as well as the best coal in the average.

A recommended method of obtaining a nearly true average of the heating value of a car load of coal is the following. In unloading the car throw, at short intervals, a shovelful of coal to one side—preferably on a clean-swept concrete floor—until by the time the car is unloaded there is a pile of about 1,000 pounds of coal laid aside for the purpose of sampling. This pile should then be pounded down until the whole mass consists of small pieces. After mixing well make two piles of the original by alternate shovelling. Take one of these piles and pound the coal still finer. Mix and divide in two. Discard one pile. Mix the coal in the other pile and pound it down. Continue with the process of dividing until there is left only a small amount of fine sized coal. This should be carefully collected and placed in jars to be sent to the chemist.

Analysis of Coal from Different Mines

The composition of coal varies greatly in different mines and even in different sections and seams of the same mine.

Anthracite may have 90 per cent fixed carbon and 3 per cent volatile matter, while Lignite may have only 50 per cent fixed carbon and 40 or 50 per cent volatile matter.

The following is an analysis of coals taken from different mines.

Place	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur
Hocking Valley (Ohio)	7.4	29.2	60.45	2.95	0.93
Pocahontas	0.52	23.9	74.2	1.38	0.52
Kentucky Cannel	...	40.2	59.8	8.81	0.96
Penna. Anthracite	1.35	3.45	89.06	5.81	0.30
South Wales	....	8.5	88.3	3.2	....
Nova Scotia	....	26.8	60.7	12.5	. .
Edmonton, Alta.	9.8 to 19.4	30.4 to 38.7	34.5 to 51.7	2.6 to 15.6	
Crows Nest	0.4 to 1.9	11.7 to 29.7	51.2 to 75	22.4	....

The user of coal should be careful neither to approve nor condemn all coal of a particular section simply because one small lot was good or bad. For instance, Western Canada coal is of nearly every quality imaginable and because some is bad it does not mean that all is bad.

Prevention of Smoke

Smoke consists of particles of unconsumed carbon which give to the gases a color ranging from light grey to dense black. It is caused by the lack of sufficient air at the proper temperature at the point where the volatile gases from the coal should be burned, with the result that the gases are only partly burned and carbon is set free.

There is a common belief that smoke coming from a chimney is a great waste of fuel. This is not borne out by tests as smoke at its very densest does not contain more than two per cent of the fuel. A boiler may show very good efficiency even if the stack is smoking. There is a waste, however, and it should be prevented if possible.

There are two great objections to smoke.

First: It ladens the surrounding atmosphere with particles of black dust, which upon settling discolors everything it comes in contact with and gives everything a dirty appearance. Many cities enforce ordinances providing penalties to be inflicted upon those plants which are consistent smoke producers.

Second: Where there is smoke there is soot and soot collects in the tubes. Soot is claimed to be about five times as good an insulator as asbestos. It can be easily seen what the effect of a thick coating of soot in the tube will be in the transmission of heat from the flue gases to the water in the boiler.

Under these circumstances it is very important that every engineer should study the best methods of smoke prevention without destroying the efficiency or capacity of the boiler.

Smoke may be caused by (1) character of fuel, (2) improper method firing, (3) poor furnace design, (4) lack of sufficient draft and (5) insufficient furnace capacity.

Much depends upon proper furnace design. The problem of attaining efficient and smokeless combustion resolves itself into three requirements, namely: the mixing of the unburned gases with the proper amount of air for combustion, the allowance of time for combustion and the maintenance of high furnace temperatures, all of which depend upon correct furnace design.

One of the causes of insufficient air is the method employed by careless firemen in their method of stoking. Coal is fired intermittently and often in large quantities at a time and the distillation proceeds at so rapid a rate that enough air cannot be introduced into the furnace to burn the gas.

A good method of hand firing is to have the fire bed even and void of all holes. Keep the fire bright and fire only small quantities at a time. In this way the air has a chance to get heated and mix with the volatile matter of the coal and cause it to burn.

A common cause of smoke of which the fireman has no control is that there is not sufficient distance allowed between the grates and the boiler shell. The flames containing unburnt carbon strike the comparatively cold surface of the boiler shell and are cooled below the ignition point before the carbon is consumed.

Properties of Air

Water is a chemical combination of two gases, namely: Hydrogen and Oxygen. As is the case in all chemical combinations, these two gases are chemically united in such a way that an entirely different substance is formed having different properties from either of the two original gases.

Air on the other hand is not a chemical combination but simply a mixture of gases, each existing separately. These gases are nitrogen, oxygen and a small percentage of several other gases, such as carbon dioxide, water vapour, etc.

The mixture by volume consists of 20.7 parts oxygen and 79.3 parts nitrogen, and by weight, 23 parts oxygen to 77 parts nitrogen.

Air, like all other gases, expands when heated. It expands 1/491.2 of its volume at 32° F. for every increase of 1°F. and its volume varies inversely as the pressure. This explains why a larger fan must be used when using induced draught than when using forced draught to handle the same weight of air.

Nitrogen being an inert gas, it does not enter into chemical combination in a furnace and is a hindrance so far as furnace work is concerned.

Air Required for Combustion of Coal

In every 100 pounds of air there are 23.15 pounds of oxygen.
12 pounds of carbon requires 32 pounds of oxygen for complete combustion.

1 pound of carbon requires $\frac{32}{12}$ pounds of oxygen for complete combustion.

1 pound of carbon requires $\frac{32}{12} \times \frac{100}{23.15} = 11.52$ pounds of air for complete combustion.

But as coal is not pure carbon let us take a sample consisting of, say, 77.43% Carbon, 4.8% Hydrogen, 6.53% Oxygen, 1.49% Sulphur, 1.28% Nitrogen and 8.47% Ash and compute the theoretic volume of air required for complete combustion, which can be computed by the following formula.

Lb of air per lb. of coal =

$$11.52\,C + 34.56\left(H - \frac{0}{8}\right) + 4.32\,S,$$

where C, H, O, and S are the proportional parts by weight of carbon, hydrogen, oxygen and sulphur, from the ultimate analysis of the coal. Hydrogen combines with eight times its weight of oxygen, therefore it is assumed that hydrogen equivalent in weight to one-eighth of the oxygen in coal will not require oxygen from the air. Substituting the given proportion of C, H, O and S, the formula becomes

Lb. of air per lb. of coal =

$$11.52 \times 0.7743 + 34.56\left(0.048 - \frac{0.0653}{8}\right) + 4.32 \times 0.0149 = 10.36$$

and as 1 lb. of air at 62 deg. F. has a volume of 13.14 cu. ft., 10.36 lb. would occupy a volume of $10.36 \times 13.14 = 136.1$ cu. ft.

This is theoretically the proper amount of air under ideal conditions, but such conditions are not obtainable in a power plant furnace.

If we attempt to obtain the ideal we are liable to supply insufficient air with the result that a part of the coal will burn to carbon monoxide, and thereby only produce about one third of the heat it would produce if burnt to carbon dioxide.

Even if we did supply the exact amount of air we have no guarantee that the air will mix properly with the coal and all coal receive its share of oxygen.

It is found that an excess of about 40 per cent of air gives the best results, that is, about 15 pounds of air is required per pound of coal burnt.

Care should be taken, however, that too great a quantity of air is not admitted in excess of that required for complete combustion. It is of no heating value and robs the furnace of

the heat required to raise its temperature from room temperature to stack temperature—a difference of somewhere in the neighborhood of 400 degrees.

Care should always be taken that as nearly as possible, the correct amount of air is supplied the furnace. This can be ascertained by testing the flue gases with an instrument known as a CO_2 recorder.

When oxygen burns with carbon, it forms carbon dioxide. The carbon dioxide gas increases in weight over the original oxygen by the amount of carbon added, but, strange as it may seem, it has just exactly the same volume as the original oxygen had.

The nitrogen passes through the furnace unchanged and therefore its percentage volume is the same.

Now we know that air by volume is 20.7 per cent oxygen and 79.3 nitrogen. If we pass just the correct amount of air through the furnace so that all the oxygen is burnt to carbon dioxide, then we must find in our flue gases just 79.3 per cent nitrogen and 20.7 per cent carbon dioxide, or, as it is generally written, CO_2. Thus it can be seen that with ideal conditions 20.7 or roughly 21 per cent CO_2 is the maximum percentage obtainable and represents perfect condition. If it were not for the difficulty of obtaining the proper mixture throughout all the coal this would be the proper percentage to aim to obtain, but owing to conditions, a percentage of from 14 to 16 gives the best results.

We have learned that we may expect to find in the flue gases nitrogen, carbon dioxide and also oxygen, if there is an excess of air. We may also find carbon monoxide if there is a deficiency of air or if the air does not reach in sufficient quantities all parts of the coal. There may also be a small percentage of sulphur dioxide, but it will be so small that it is not considered.

Heat Lost in Chimney

The flue gases leaving the boiler must be at a higher temperature than the water in the boiler. Supposing a steam pressure of 150 pounds gauge pressure is being carried in the boiler, then the temperature in the boiler must be 366°F. and the minimum temperature of the flue gases could not be lower than this figure. In practice the best results would be obtained with a stack temperature of between 450°F. and 500°F. There are a number of causes that might result in a much higher temperature, such as dirty tubes and shell, insufficient or broken down baffling, or an insufficient number of passes of the gases through the tubes.

We have stated that about fifteen pounds of air for every pound of coal burned give the most satisfactory results, but if fire doors are opened too much or holes in the fire are allowed, or there are cracks in the brick work or about the breaching, the chimney may be required to handle much more air than the amount above stated.

The actual heat passing to the stack in the best of furnaces amounts to about one-tenth of the total heat in the coal burned and it is often much greater in poorly constructed or poorly operated furnaces.

Flue Gas Analysis (S. G. Rose)

It should be apparent from what has been already said that it is necessary to ascertain the contents of the flue gases if one wishes to know that the furnace is getting the proper supply of air and that the furnace is functioning properly so that the maximum heat is being derived from the coal.

For this purpose a number of instruments have been constructed, the most popular of which is the Orsat Analyser, which we will endeavour to describe.

Fig. 5 is a portable Orsat Analyser. This analyser is enclosed in a case which is easily portable. The case contains a measuring tube or burette "A", usually of 100 C.C. capacity, although in the smaller types it may be of only 50 C.C. capacity.

If the purpose is simply to ascertain the amount of CO_2 present in the gases, only one pipette "B", is contained in the case, but if it is also required to ascertain the percentage of CO and unburned oxygen present, then two additional burettes, "C" and "D", must be added together with probably an extra one for the final washing of the gases.

The burette "A" is water jacketed and graduated from 0 to 20 C.C. The pipette "B" contains sodium potassium (caustic potash), dissolved in three times its weight of water, and is used for absorption of the CO_2. Small glass tubes or steel wool, fill the inner chamber of this pipette which exposes a larger area of surface to the flue gases. Pipette "C" contains pyrogolic acid dissolved in sodium hydrate solution, in the proportion of 5 grams of pyrogolic acid to 100 C.C. of the sodium hydrate solution, and is for the absorption of oxygen. Pipette "D" contains a solution of coprous chloride for the absorption of CO. Pipettes C and D each contains small glass tubes or steel wool, as in the case of Pipette "B", and inside the Pipette "D" is inserted copper wire to assist in maintaining the strength of the coprous chloride solution.

Pipettes "C" and "D" are each fitted with a rubber bag. When the gas is driven into these pipettes from the burette, the air on the outer side of the solution is forced over into these bags and when the gases are drawn off the pipettes the air returns again into the pipette. As the solutions in these pipettes absorb oxygen, the exposing of these solutions to the air would soon make them useless. The bottle "F" is called the levelling bottle and contains water, and is attached to burette "A" with rubber tubing. The gas in burette "A" can be forced out by raising this bottle and letting the water flow into the burette and it can be drawn in by lowering the bottle and letting the water flow out of the burette into the bottle. A filter is generally placed in the pipe through which the flue gases have to pass before entering the machine. This filter is a glass tube filled with some filtering material which will prevent the particles of soot in the flue glass from entering the small tubing or burette.

If soot or fine particles of dust get into the small bore of the glass tubing the machine will become clogged and the graduations on the measuring burette will be obliterated.

"H" is a hand bellow or gas pump made of rubber and fitted to the filter at one end and to the sampling pipe at the other, and is connected to same with suitable rubber tubing. This hand pump should be of ample size and well constructed; otherwise, it will give a lot of trouble. It is fitted with two rubber valves, inlet and outlet, and these should be kept clean, as particles of soot and dust prevent their seating properly. B_1, C_1, and D_1, are cocks; A_1 is a

three-way cock. These cocks need attention and should be kept working smoothly with a thin film of vaseline inside, then worked around and any surplus wiped off, care being taken not to allow any of the vaseline to enter the small glass tubing. If the machines are to be left idle any length of time, these cocks should be thoroughly cleaned or they will corrode and stick.

The greatest source of inaccuracy of the machine is air leaks and great care should be taken that all connecting rubber tubing is free from leaks, also around the cocks, especially the three-way cock A_1.

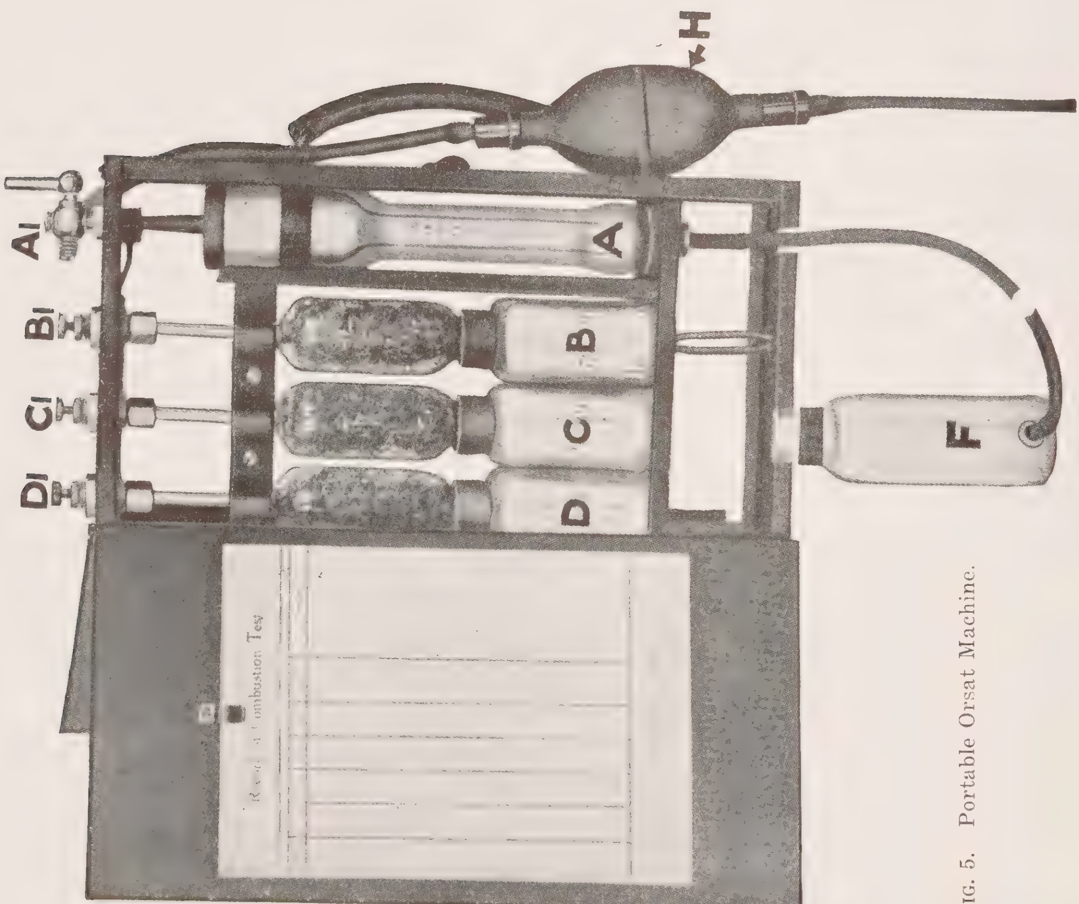

FIG. 5. Portable Orsat Machine.

To operate the apparatus, set up and fill the levelling bottle about two-thirds full; also fill with water the glass casing in which the burette is placed. Put enough sodium hydrate solution in pipette "B", so that when the solution is drawn up to the mark at the top of the pipette there will be a surplus of the solution in the outer casing of the pipette, but not enough to overflow when 100 C.C. of the flue gas is forced over by the raising of the levelling bottle. Also, put in the reagents in pipettes C and D, gauging the amount in the same manner. Care should be taken not to draw over any of the reagents into the water in the burette, or an incorrect reading would be shown. If any of the reagents are so drawn over, the water in the levelling bottle should be renewed, also the cocks should be cleaned to prevent their sticking.

Test the apparatus for air leaks by closing to atmosphere and raising the bottle, thus putting the apparatus under pressure. If no air leaks are present the water will remain at a set place, but if air leaks are present, the water will gradually rise in the burette.

To connect the apparatus to the flue gas passage from which a sample is to be drawn, insert a piece of gas piping (one-quarter inch iron pipe) into the gas passage before it enters the uptake. If it is a water tube type of boiler, do not place the sampling pipe in the uptake or you will probably get a low reading of CO_2, as invariably there are leaks around the connection of the uptake on the smoke box.

Care should be taken to get the sampling pipe in the direct flow of the flue gas and where the damper does not interfere with its flow. Do not use a pipe with holes along its whole length, or you will probably get the sample only from the first two or three holes in the pipe. These holes being near the brickwork would make it possible for the gases to be diluted by an infiltration of air. When the pipe has been placed in its proper position, connect it to the apparatus by means of a rubber tube, of which the pump or bellows is a part.

Now place the three-way cock so that its passage is open to the atmosphere, raise the bottle and fill the burette with water, displacing the air, and pump the gas through again until all the air is displaced from the pipe and connections. This done, turn the three-way cocks so that the gas passes into the burette. Now lower the levelling bottle low enough to cause the water level to fill below the zero mark, by using the pump the burette may now be filled with flue gases. If the pump is given a few more extra strokes no harm will be done, as part of the gases under pressure of the pump will pass out through the water in the levelling bottle. You now have a burette full of the flue gas and to ascertain the percentage of CO_2 in this volume, open the three-way cock A_1 to the atmosphere and carefully bring the levelling bottle up so that the water in the burette is at zero. Then close the three-way cock A_1 and open cock B_1 and raise the levelling bottles, thus bringing the water up in the burette until it reaches the small mark at the top of the burette. This operation has now forced the gases over into the pipette B which absorbs the CO_2 from the gases. Next, lower the bottle and the gases will be drawn over into the burette, but while doing this, watch carefully the solution rising in the pipette B until the solution reaches the small mark on the tube, at which point stop the flow of gases. Repeat this operation three or four times, or until no further absorption is seen to take place, then close the cock B, being careful to note that the solution is up to the mark on the tube, ready for the next test. Bring the levelling bottle close to the burette and raise or lower it until the water now in

the burette and the water in the bottle are the same level. The percentage of gas in the form of CO_2 which has been absorbed in pipette B can now be read on the graduated scale on the burette.

If the percentage is below 15 per cent it is not likely that any CO will be present and the operation just described is about all the analysis that is necessary, but if more than 15 per cent of CO_2 is shown present, a test should be continued for O and CO.

After getting the CO_2 as described, to proceed, open cock C and pass the gas into pipette C a number of times until no further absorption is indicated by the readings before and after passing it into this pipette. When the oxygen is all absorbed, note the readings on the burette and thus ascertain the percentage of oxygen in the gas. To ascertain the percentage of carbon monoxide, open cock D and pass the gas into the pipette D. It should be noted that it will take a much longer time to absorb the CO than did the other gases, and also, that as this solution also absorbs O, care must be taken that all this gas has been absorbed before passing the gas into this pipette. The solution for the absorption of CO deteriorates and to get success, follow the directions of the manufacturers of the solution as found on the label of the bottle.

Draft

Draft is the flow of air from an area of high pressure to that of a lower pressure. When we speak of a draft in connection with a furnace we have in mind the passage of air with its rate of flow through the furnace on its way to the chimney.

Owing to friction, eddy current and other causes—the greatest of which is the fuel bed—the draft decreases between the inlet and outlet to the chimney.

Combustion, generally speaking, is the union of fuel with the oxygen of the air. The supply of oxygen is just as important and essential as the coal.

The air is supplied to furnaces by three methods, (1) the chimney (natural draft), (2) forced draft and (3) induced draft. Chimney draft is caused by the difference in pressure downward inside the chimney and that outside the chimney. This difference is caused by the heating of the gas before it enters the chimney. Gas expands at the rate of about two per cent for every 100° Fahrenheit that is added to its temperature. It is obvious that when the gas is expanded, the hot gas must become lighter per volume than the cold gas. The cold gas outside the chimney will therefore press down with greater intensity than the gas within the chimney with the result that the hot gas is pushed up. In order to reach the area of hotter and lighter gas, the cold gas must flow through the furnace. The greater the difference in density of the two gases the greater will be the draft.

Draft is materially affected by atmospheric conditions. A better draft can be obtained in cold weather than in warm. It is also better in clear dry weather than in hot sultry, or foggy weather. Wind also has an influence on the draft.

Forced draft is caused by means of a fan blowing air through an air duct into a closed ashpit and forcing the air up through the fire.

Induced draft is created by means of a fan, or, as in the case of a locomotive, a steam

jet. These are placed at the base of the chimney and draw the gases from the furnace, forcing them up the chimney. For the same amount of draft the induced draft fan must be larger than the fan used in the forced draft for handling the same weight of gas, the reason being that the gases entering the stack are much hotter than the air entering the furnace and therefore have a larger volume.

Draft is considered in furnace work as the difference in pressure in some particular section of the furnace or chimney, compared with the pressure of the atmosphere surrounding the furnace. For instance, we might state that in a particular plant the draft under the grates is 2 ounces, over the fire .01 ounces and at the base of the chimney —1.5 ounces. In the first instance the pressure is greater than the atmospheric pressure, while in the last instance the pressure is less than atmospheric pressure, that is, in the chimney there is a partial vacuum.

The usual method of measuring draft is by means of what is known as a U tube. The simplest kind is a glass tube about a foot long and bent into the form of a U. This tube is partially filled with water. It is attached to the chamber in which the draft is to be measured by means of a piece of rubber tubing and iron pipe, the pipe being inserted through the chamber wall so that its end is open to the chamber. Supposing the U tube is connected to the ashpit when forced draft is used, the pressure due to the forced draft will force the water down the attached leg of the U and up the leg open to the atmosphere. The water level in the two tubes will then differ from each other. Supposing, that we found the difference of water level to be, say, two inches, this would be registered as carrying two inches of draft, which would be the equivalent of 1.162 ounces more than atmospheric pressure.

If the tube were attached to the chimney base, the water in the leg of the U tube attached to the chimney would rise higher than the other leg, and the difference in level would denote the quantity of negative pressure at the chimney base.

Fig. 6 is a more refined type of U tube than the one we have just explained and more accurate readings of draft may be obtained from the same. As in the former type of U tube, the latter tube is attached to the chamber of the furnace by a rubber tube leading from A.

Figure 7 shows what is known as a "differential draft gauge". It will be noted that the tube is situated on an inclined plane. The measure of the draft in all gauges is the vertical difference in the height of the water in the tube. To rise vertically one inch, the liquid must travel ten inches along the inclined tube, therefore slight changes in draft can be easily noticed. A thin oil that does not evaporate and has less capillary attraction is substituted for water as the liquid. This oil is generally coloured to make it more visible.

The differential draft gauge is desirable for measuring comparatively small pressure difference of the gas in the several portions of the furnace and boiler. For instance, it can be used to indicate the drop in pressure through the fuel bed. An increase in the difference would show that the fuel bed was becoming thicker or becoming clogged with clinkers and ash.

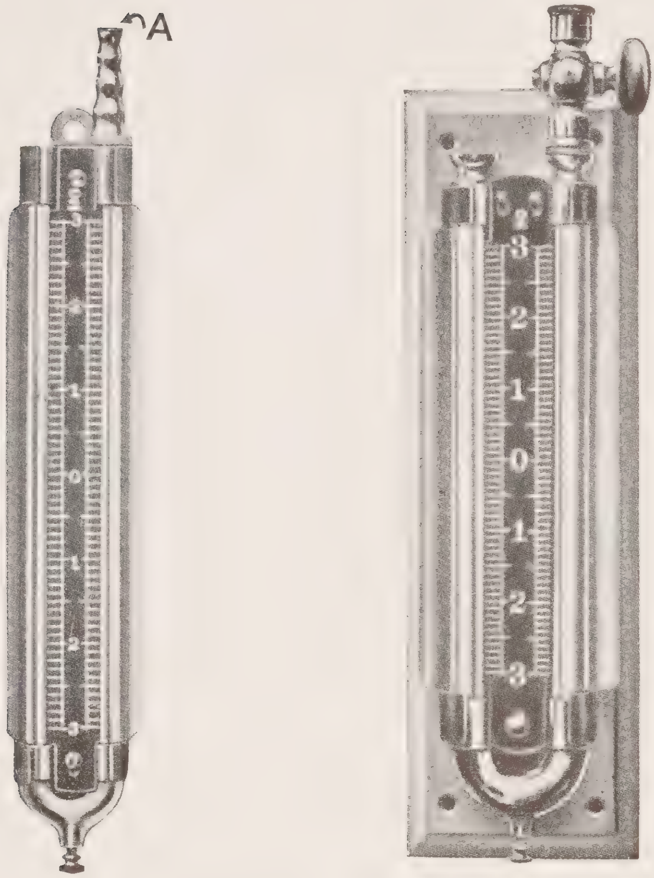

FIG. 6. Draft Gauge.

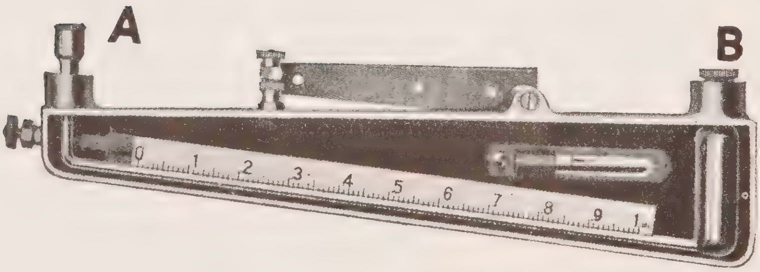

FIG. 7. Differential Draft Gauge.

Mechanical Draft

Except for variation in atmospheric conditions, natural draft, that is, draft created by a chimney, is constant and cannot be increased beyond a certain point, so that it is impossible to force the fires to any great extent above their rating. Below this point natural draft can, of course, be regulated by means of dampers.

Mechanical draft, that is draft created by fans, on the other hand has a much larger amount of variation, depending to a large extent on the speed at which the fans are run. Mechanical draft as already stated, may be forced draft or induced draft, but in both cases it is dependent on fans as to its intensity.

Where batteries of boilers are used, it is usual to have a large fan and air duct of sufficient volume for all the boilers and a branch duct leading from the main duct to each boiler. This branch duct is supplied with a damper for shutting off or regulating the quantity of air reaching each furnace. The air duct should be as nearly air tight as possible, of sufficient size and fitted with proper dampers. No sharp bends should exist as they have a strong tendency to increase friction.

For individual boilers, forced draft is sometimes created by a fan built into the brick work as shown in Fig. 8. It is usually driven by a small steam turbine.

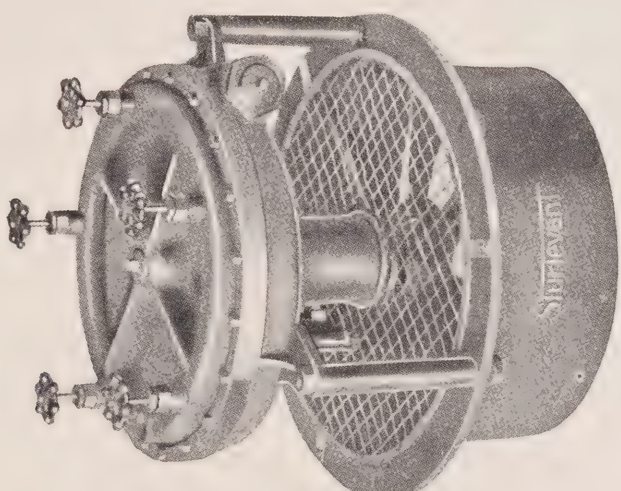

Fig. 8. Forced Draft Fan.

Induced draft is created by a fan near the base of the chimney. It is often used in plants which are equipped with economizers.

The disadvantage of induced draft over forced draft is that the fan must handle a larger volume of air because the air is expanded. Also, the fan is liable to cause more trouble on account of the heat from the gases. The bearings of the fan must necessarily run at a higher temperature than in the case of forced draft. Induced draft has the advantage, however, of being cheaper to install as no air ducts are required.

Frequently the chimney, when using induced draft, is of no great height, but only sufficiently high to carry the smoke above the surrounding buildings.

Draft Control

Natural draft should be controlled by dampers rather than by the ash-pit door. Closing the ash-pit door has a very bad effect as it shuts off the air which is supplied through the fuel bed. The ash on the grate and the grate bars become heated and clinker and warp the grates. Furthermore, a partial vacuum is formed within the furnace walls and an amount of air out of proportion to the fuel burned, enters through all openings such as cracks in the brick-work and furnace doors and by infiltration of air through the brick itself, which by the way, is usually much greater than one might suspect.

If the breeching damper is used, no such difference in pressure exists and no infiltration of air would take place.

Breeching dampers are controlled by hand in many boiler plants. In such plants levers should be arranged at the front of the boiler for the convenience of the fireman.

It is always best to operate a boiler furnace, whether it be natural, forced or induced draft, with as nearly atmospheric pressure as possible directly over the fire. If a pressure of less than atmospheric pressure is carried there is always a leakage of cold air into the furnace, while if more than atmospheric pressure is carried there is the danger of forcing the hot gases into the porous brickwork and crevices and thereby injuring the lining. Of the two evils the latter is the worse and it is a good rule to carry a very slight minus pressure over the fires of from .01 to .02 inches of water. This can only be done in the case of natural draft by means of manipulating the damper and never by opening and closing the ash-pit door.

It should be always kept in mind that the greater the difference of pressure over the fire and at inlet of the stack, the greater the velocity of the gases will be and, therefore, their time of contact with the heating surface of the boiler will be less and consequently less heat will be delivered from the gases to the boiler. A rise in the temperature of the stack gases would be an indication that this may be taking place.

Automatic Damper Controls

Frequently dampers are automatically controlled by a mechanism that opens or closes the damper as the steam pressure is reduced or raised in the boiler.

There are a great many of these appliances to be found on the market and for the most part they give good results in operation. They are controlled primarily by the pressure in the main steam piping, and the damper operating mechanism so controlled is, in turn, operated by the pressure of a fluid. The following illustration, Fig. 9, will serve to show the general construction of a damper regulator which is sensitive in its operation. This appliance is known as the Thompson automatic damper and pressure regulator. The principle upon which this works is essentially as follows:

The pressure is taken directly from the boiler, steam pipes, or in cases where a series of boilers are to be controlled, from the main steam header, and led directly to the under side of the piston, shown near the fulcrum of the long levers. The piston rod is carried through guides, operated on the under side of the long lever, which is balanced on the opposite end by weights, as shown. Variations in the steam pressure cause the piston to

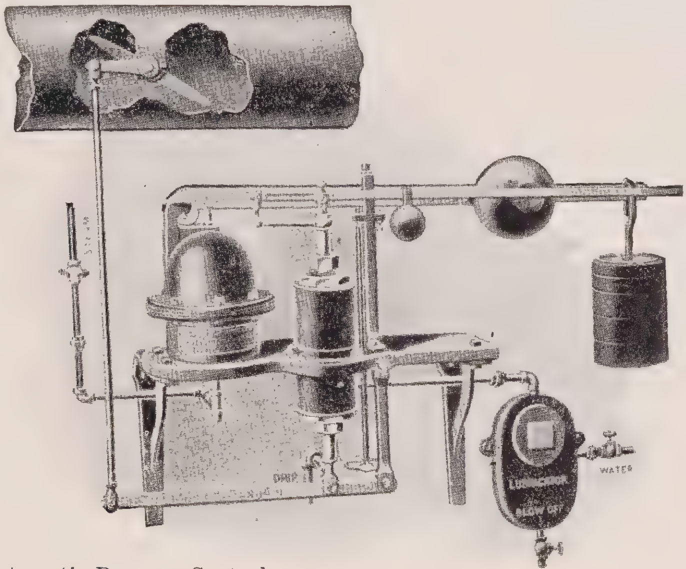

FIG. 9. Automatic Damper Control.

move up and down, which in turn, moves this corresponding lever. Attached to this first lever is a second lever which operates a pilot valve. This pilot valve controls the flow of the operating medium (water usually, from city main), to a second cylinder, which is also provided with a piston connected to a lever near the bottom of the apparatus. This latter lever is then connected to the damper or dampers, to be operated through connecting links or chains. The use of chains here requires the addition of counterweights on the damper lever.

In addition to operating the flue dampers, the above-described apparatus is frequently connected so as to control the mechanical draft to the boiler. The blower may be operated in this case either by a steam engine or an electric motor. In case of the steam-operated fan, a regulating valve is inserted in the steam supply, and the regulator connected to this. In case of a motor, the regulator is connected to a suitable motor controller.

Damper Setting (Cochrane Handbook)

According to Osborn Monnett dampers for horizontal return-tubular boiler should occupy the full width of the available opening and have a free area 25% in excess of the combined tube area. No type of damper plate that restricts the opening should be used.

For water tube boilers, a free opening of one quarter the grate surface should be provided and the dampers when wide open should hang in such a manner as not to obstruct the movement of the gases. He recommends that no damper be placed in the main breeching.

To calibrate the damper, connect a differential draft gauge around the damper. Place the damper in the extreme closed position, open gradually and mark the position when the draft gauge is first affected. Continue opening the damper until the gauge registers no draft drop. Mark this position. Adjust the damper to work between these two positions.

Damper controls are preferably placed at the boiler front, where they can be easily reached and used by the fireman.

There are two classes of automatic damper regulators; first, machines that move the damper for slight changes of steam pressure, the movement being more or less proportional to the change of pressure; and second, machines that swing the damper between extreme positions when the steam pressure changes. Hays says that the first class is the better. The second does not meet the requirements of economical combustion. With the damper open, CO_2 percentage falls, due to air excess; with it closed, CO forms, due to lack of air. Machines of the first class may not make as perfect a steam pressure curve as the second, but will show better economy.

The U.S. Bureau of Mines says to use high drafts with high rates of combustion, and low draft with low rates of combustion. It is impossible to get a high rate of combustion with a low draft, but very frequently high draft is used for low rates of combustion, using 30 to 40 lb. of air where 15 should be used. Regulate the draft by the damper. Arrange the latter so that the fireman can easily set it from the floor level.

Many serious cases of draft trouble could be cured by adjusting the boiler dampers to equalize the draft among the boilers. To equalize the draft among the boilers, get the fires all in standard condition, that is, the same thickness, free from air holes and clinkers. Adjust each boiler damper to the standard draft. Thereafter the main breeching damper alone should be used to regulate the draft to meet the load.

Change the position of the damper gradually. If the steam pressure is high, the damper should not be closed off entirely in order to let the pressure drop, then opened full to get the pressure up. This causes the draft and the air supply to vary excessively. Poorly adjusted automatic dampers cause similar variations.

Automatic Combustion Control

Fig. 10 is a diagram which shows not only how the damper can be controlled by a master regulator, but also how the master regulator can control the fan speed and stoker speed and have a balanced draft under all conditions, through the medium of chains and pulleys. Adjustments made are such that there may be for all conditions of load, a most favourable furnace pressure. The apparatus is adjusted to maintain a correct relation between fuel and air supplied in accordance with the steam demand and at the same time prevent undue furnace suction variation by properly synchronizing the operation of the forced draft fan with the movement of the boiler damper.

Bailey Boiler Meter

The Bailey boiler meter combines a differential draft gauge with a steam flow meter enclosed in the same case, both recording on one circular chart. The pressure drop in the boiler gas passage is an indication of the quantity of air passing through the boiler, and the pen recording this pressure is set to record just ahead of the steam flow pen. The instrument is so adjusted by means of CO_2 determinations that when the two lines practically

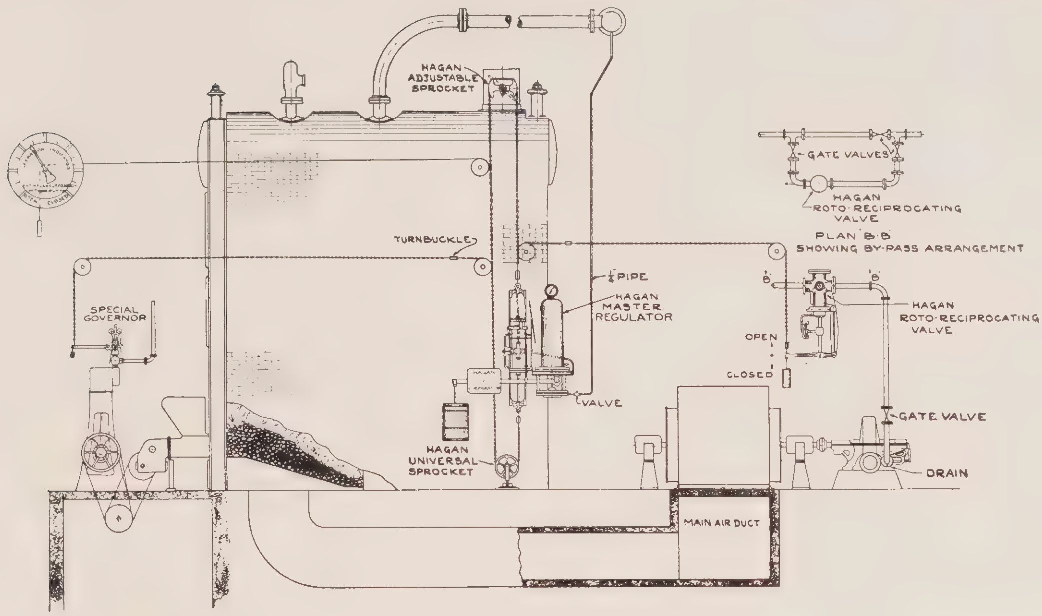

FIG. 10. Automatic Combustion Control.

coincide, the air is in the proper proportion for the load on the boiler. The steam record is made as a percentage of the rated capacity of the boiler.

The amount of air required to produce a given amount of heat is practically the same for all forms of fuel, from coal to natural gas. By comparison of the steam flow with the air flow, it is possible for the fireman to judge how perfect combustion is and to prevent undue losses in either excess air or unburned gases.

Hand Firing

There is an art in the firing of boilers. The hap-hazard method of throwing on the grates a few shovelfuls of coal at times, is not economical, to say the least, and is almost sure of creating large volumes of smoke.

As all the smoke emanates from the volatile gas of coal, there is little trouble from this source when burning anthracite (hard) coal, as it contains only a small percentage of volatile matter. Anthracite coal should be fired evenly and in small quantities at a time. Fire tools should be used as little as possible.

Bituminous coal, on the other hand, has a large percentage of volatile matter and therefore, if not fired in the proper manner, will cause large volumes of smoke. There are three well known methods of firing soft coal which are usually followed, namely: coking and spreading and alternating.

In the coking method, the coal is thrown in the front part of the furnace and left there until the volatile gases are driven off, leaving only the coke. This coke is then pushed back and fresh coal placed in the front of the furnace.

The reason for this procedure is that when the coke in the back of the grates burns, it produces intense heat which is sufficient to ignite the volatile gas driven off the fresh coal at the front, with the result that all gases and the carbon they contain are completely burned, thereby adding to efficiency of the furnace and preventing black smoke and soot.

Compared with the other two methods, the coking method has the disadvantage that the door must be longer open, thus allowing an excess of cold air over the fire.

In the spreading method, which is the most common method of firing, the green coal is spread in very thin, even layers over the fire, in such a manner that no part of the fire is chilled below the ignition point of the gases.

The disadvantage of this method lies in the fact that a caking fuel may fuse and prevent sufficient air for proper combustion of the fresh coal fired on top of it. Considerable skill, also, is required in the placing of fresh coal on the thin spots.

The alternating method is to add coal to one side of the grates at a time. With this method there is a bright burning coal on one side of grates while the green coal on the other side is coking. The bright burning coal will create sufficient heat to burn the volatile gas.

No matter what kind of coal or what method of firing is used, the motto should be "fire light and often" and do not have the fire door open any longer than absolutely necessary. Keep the fuel evenly distributed over the grate and do not allow any thin spots to exist. Keep the ash-pits bright. If they become dark it is a sign clinkers are forming and the fires need cleaning.

Clinker (U.S. Bureau of Mines)

The Bureau of Mines names the following as usual causes of clinker trouble: thick fire, excessive stirring of the fire, burning coal in the ash-pit, much slack in the coal, closed ash-pit doors and the preheating of air admitted under the grates. Any coal will clinker if the ash is heated to the fusing temperature. Ash in an oxidizing atmosphere, as near the bottom of the fuel bed, has a higher melting point than in a reducing atmosphere, as near the top of the fuel bed. The difference is as much as 260°F.

A thick fuel bed causes clinker trouble as often as all other causes put together. A thick fuel bed cuts down the air supply and permits the ash to become heated. Air in passing through the grates and the fuel bed absorbs heat from the grate bars and the ash upon them, thus keeping them relatively cool. The fusing temperature of the ash is lowered by the reducing atmosphere in the upper layer of the ash. In a thick bed the ash mixes with the burning coal to a greater height, and the reducing zone is nearer the grate, due to the lower velocity of the air. In a thin fire the reducing zone is confined to the top inch or two of the fuel bed, where bits of ash are few and far apart, and cannot fuse together.

The second greatest cause of clinker trouble is stirring of the fire. If a caking coal is fired in large amounts it fuses. Breaking up the crust with a bar brings the ash to the upper part of the fuel bed into the reducing atmosphere, where it fuses more readily and produces clinker. Careless levelling of the fire with the rake may produce the same result. Burning coal may be shaken through the grate when levelling the fire or when attempting

to fill up the holes with fresh coal. This overheats the grate bars and the ash, and clinker is very liable to result.

A large quantity of slack tends to fuse, cutting down the air. The result is the same as a thick fire, the grates and layer of coal are overheated. Closed ash doors and preheating the air have an effect similar to the above and the grates and ash are overheated. With coals forming large pieces of clinker it is always a question whether more heat is not lost by frequent cleanings of the fire than by the bad condition of the fuel bed on account of its clinker. Overall efficiency drops with increase in ash percentage. High ash reduces the capacity of the boiler by reducing the rate of combustion, and also by the fact that during the time of removing the clinker combustion is almost entirely suspended.

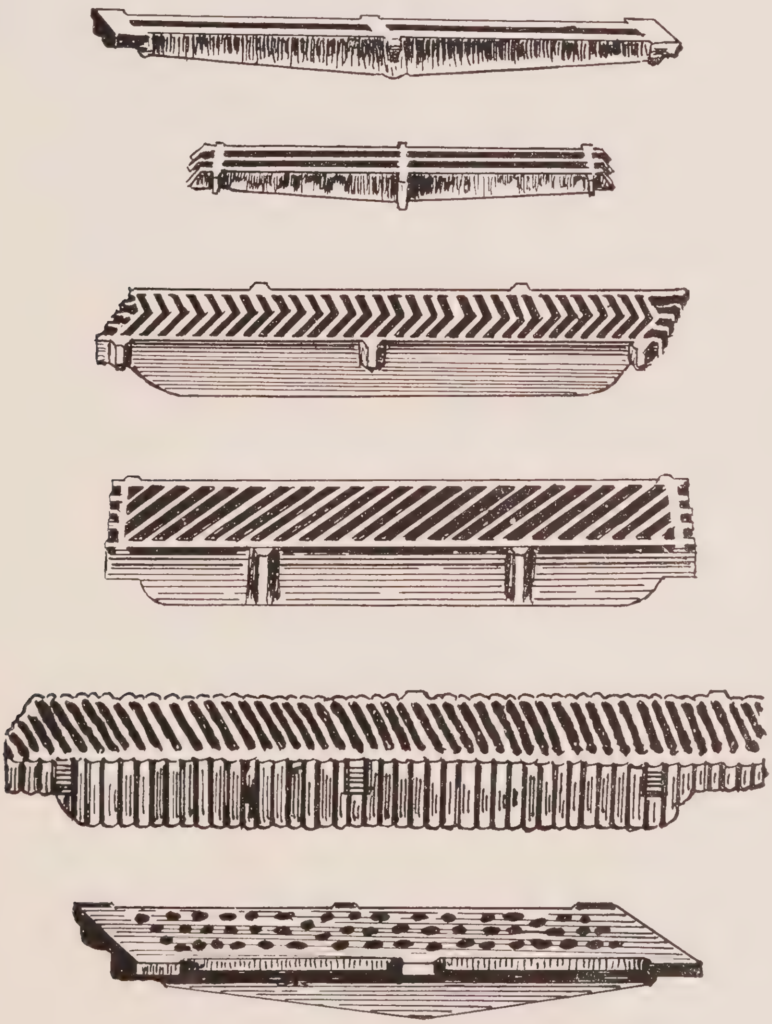

FIG. 11. Different Types of Stationary Grate Bars.

The following general suggestions are given to aid in overcoming clinker trouble: If possible find and remove the cause. Use thin fires; keep the fire bed level by placing the fuel on the thin spots. Avoid levelling with the rake. Above all, omit the slice bar. Fire small charges, thereby reducing the crust formation and the need of breaking it up. Especial care should be taken to do this if the coal contains much slack. Avoid burning coal in the ash-pit. If the pit is tight, keep water in it, otherwise blow in steam. The decomposition of the steam will absorb heat from the grates and the ash. Keep the ash-pit door open. Use the damper to regulate the draft.

Dead Plate

Just inside the door and in front of the grates, it is a common custom to have a solid plate. This plate serves as a support of one end of the grates but its main purpose is to hold the green coal while coking, when the coking method of firing is being used.

Grate Bars

Grates can be divided roughly into two classes, namely: the stationary and the shaking or dumping.

The purpose of grates is to support the fuel in the furnace and allow air to mingle with it while it is being consumed. The air is allowed to enter the furnace below the grate and through what is known as the ash-pit and hence up to the burning fuel, through openings in the grate.

Fig. 11 shows a number of different designs of stationary grates. These grates must be cleaned by dragging the ash and clinkers out through the front door.

Rocking or Shaking Grates

In order to reduce labour and to avoid opening the fire door oftener than necessary, thereby cooling the furnace, rocking grates are frequently employed. In the rocking grate the bars of the grate are made separate. These bars are attached to levers which reach to the front of the furnace. By means of these levers the fireman can give the grate bars a slight oscillating motion which breaks up the caked fuel and cleans the bottom of the fuel bed, thus giving a freer access of air to the burning fuel.

Some shaking grates are so designed that in addition to having the shaking facilities they may be dumped, which decreases the labour and time required in cleaning the fire. The grates are in two sections, making it possible in cleaning the fire to wing the live coal to one side before dumping the ash on the other side. These are known as dumping grates as illustrated in Figure 12.

Dutch Oven

For the burning of sawdust, tanbark, wood refuse or any low grade fuel of large moisture content, it is customary to use the dutch oven furnace. This furnace consists of a box-like construction of fire brick built out in front of the boiler setting and is furnished with

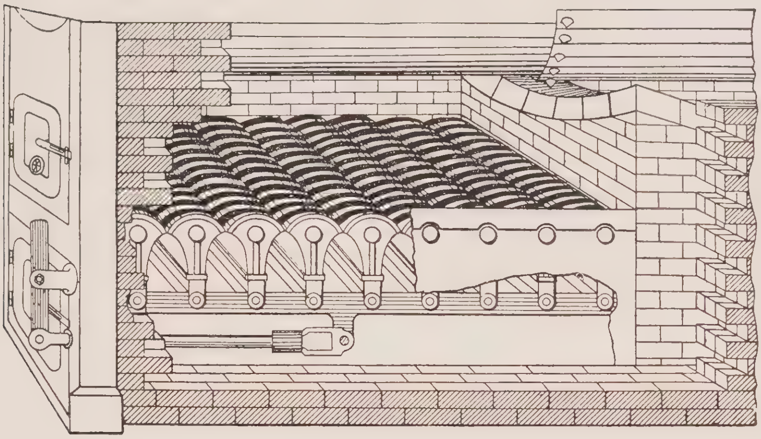

FIG. 12. Rocking or Shaking Grates.

grates in the ordinary way. The chamber is entirely surrounded by the brick work, excepting the exit side to the boiler.

While in operation the brick-work becomes intensely hot and tends to increase the temperature of the volatile gases to the ignition point.

The objection to the oven is the amount of space it occupies in the boiler room. There are modifications of this furnace setting. In some cases it is built to protrude only half its length beyond the front of the boiler, while in others it is built completely beneath the boiler, but in these designs considerable boiler heating surface is sacrificed.

Coal is sometimes burned in these furnaces, but owing to the fact that very rapid distillation takes place, it is difficult to supply sufficient mixture of air for proper combusbustion of coal. Sometimes steam jets are used to assist the proper mixture of the gases.

Hawley Down Draft Furnaces

The Hawley furnace was devised to increase economy and to lessen smoke. It has two sets of grates, one placed above the other. The upper grates are composed of a row of water tubes attached at each end to a header which is connected to the boiler. These grates thus become part of the boiler and increase the boiler heating surface. The lower grates are of the common bar type.

The air passage is constructed in such a manner that air is received over the top of the fire on the upper grate and passes down through the fuel on its way to the smoke stack. Air also travels upward through the fuel bed of the lower grate. The fresh coal is placed on the upper grate where it is partly consumed and then falls through the upper grate on to the lower grate where combustion is completed.

The volatile gases are driven off on the upper grate and passing downward come in contact with the incandescent fuel bed on the lower grate and are consumed. The combustion of these gases adds considerably to the heat obtained from the coal and prevents smoke.

Fig. 13 is a cut of the Kewanee boiler using the down draft principle. The two sets

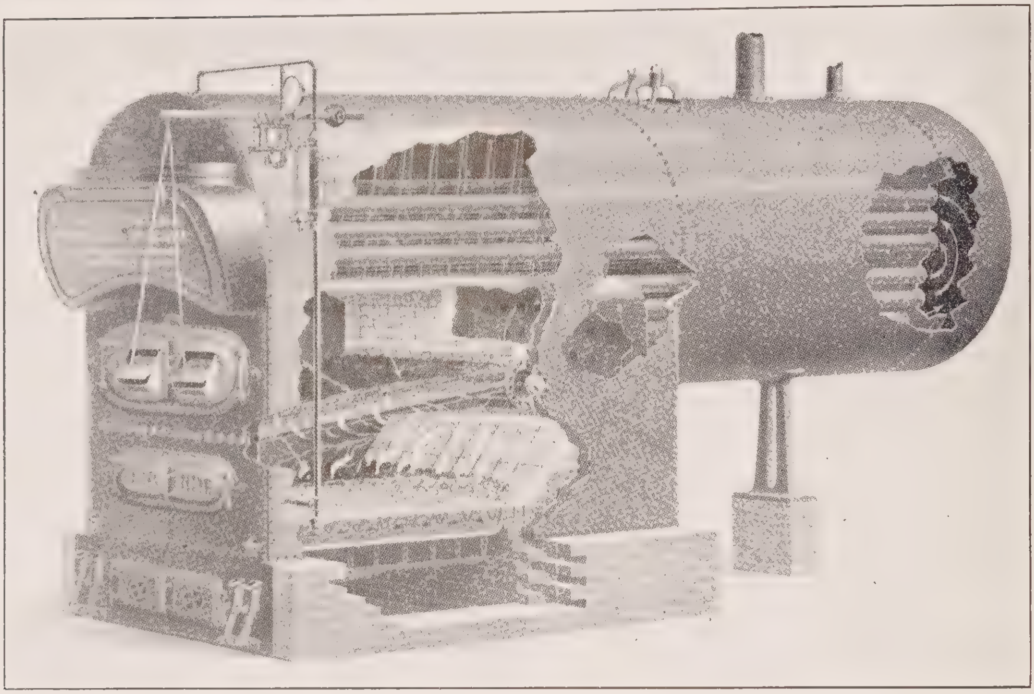

FIG. 13. Kewanee Boiler with Down Draft.

of grates are clearly shown. The green coal is placed on the upper grate through the upper door. The coal should be fired thin and evenly as in any other type of hand fired furnace.

Automatic Stokers

Up to the beginning of the present century, almost all stoking was done with the shovel, but as each year goes by more and more boilers are being equipped with automatic stokers.

Some of the advantages claimed for automatic stokers over hand firing are: (1) better control of the air supply, as no doors need be opened and a more continuous supply of air may be admitted; (2) a better control of the fuel, with higher efficiency; (3) poorer grades of coal may be burned more efficiently; (4) the burning of coal can more readily be regulated to meet fluctuating loads; (5) more nearly smokeless combustion; (6) saving in labor.

The disadvantages are the initial cost and the cost of maintenance.

Automatic stokers may be divided into three general types, namely: chain grate, underfeed and overfeed.

Only a few of these general types are described in the following pages, the list being rather long to mention them all.

The Canada Stoker

The Canada stoker is shown in Fig. 14 is claimed to be more economical than hand firing, as the fire doors need not be opened, and also, the coal is more evenly distributed over the grates.

The operating of the Canada stoker is briefly: There are usually two stokers to each boiler. Each stoker has a sectional, removable, sheet steel hopper, having a capacity of about 400 lbs. of coal, which may be readily filled by hand or other means. Directly under each hopper is a sliding feed plate actuated by an eccentric, which receives its motion from a line shaft, applied to the boiler front. The to and fro movement of this feed plate causes the fuel in the hopper to slowly work down on to a flat table surface, from whence it is gradually pushed along by the action of the feed plate, until it reaches the revolving blades of the stoker.

These blades, running at about 270 R.P.M., strike the fuel as it is fed, and it is claimed, deliver it continuously to the furnace in a manner which might be compared to a light shower of rain. The different curvature of each particular blade gives a perfect distribution of the coal over the entire length and width of the grate.

When operating, the blades are held in the radial position merely by centrifugal force, and should an unusual obstruction be encountered, the blades will swing clear back on their pivot rods, leaving the next set of following blades to sweep the obstruction into the fire. This important feature of design acts as a safety device, and prevents shock or injury to the stoker mechanism.

The blades revolve at a constant speed and independent from the feed plate and its position and do not in any way determine the quality of fuel fed to the furnace. The amount of coal supplied to the distributing blades is governed entirely by the fuel control hand wheel. Any desired rate of feed, from nothing to a ton or more per hour, may be obtained by merely turning the control wheel to conform with the load demand of the boiler. It is unnecessary to alter the speed of the stoker to feed more or less fuel.

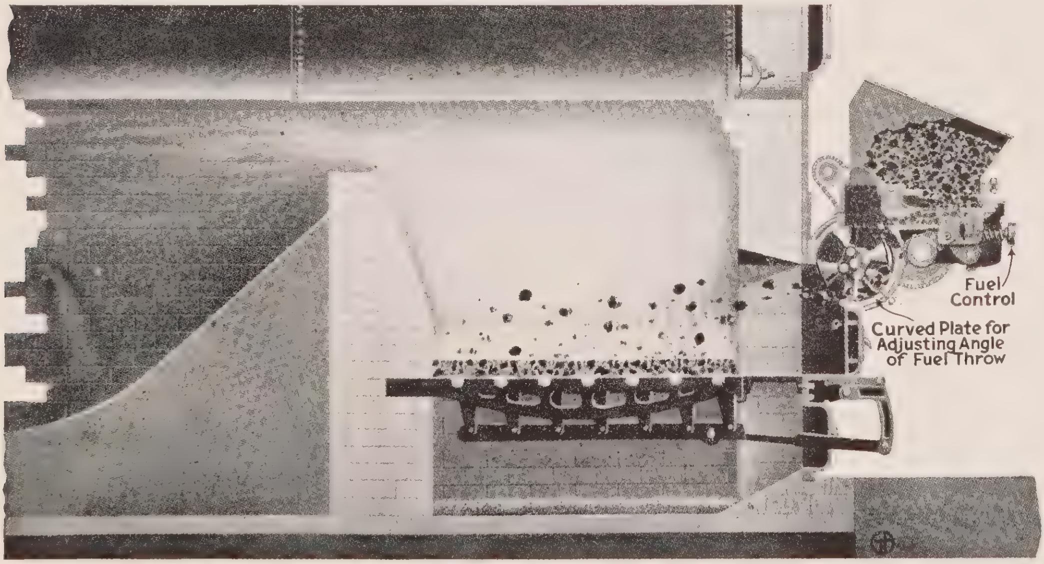

FIG. 14. Canada Stoker.

Hand Operated Stoker

The relatively large outlay required on mechanical stokers may frequently not be justified in plants of small size where a hand operated stoker may meet the requirements and avoid the drawbacks of hand firing.

The McClave hand fired stoker is designed to burn all grades and kinds of bituminous fuels. This equipment consists of heavily constructed McClave divided kicker movement grates, and McClave extra heavy cut-out bars for the removal of the ash and clinkers, and special brick lined dead plate.

The stationary bars, as well as the kicker bars, are made with removable sectional tops with shanks and are mounted in sockets in the pendant body portion of the bars. A soft

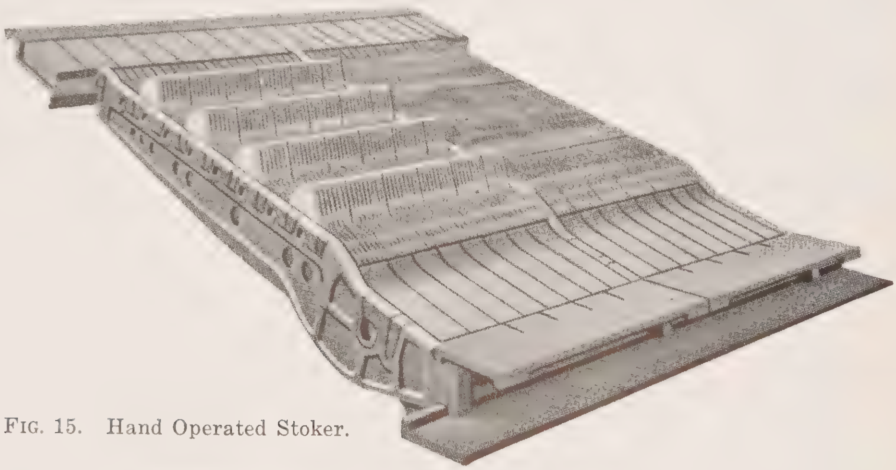

FIG. 15. Hand Operated Stoker.

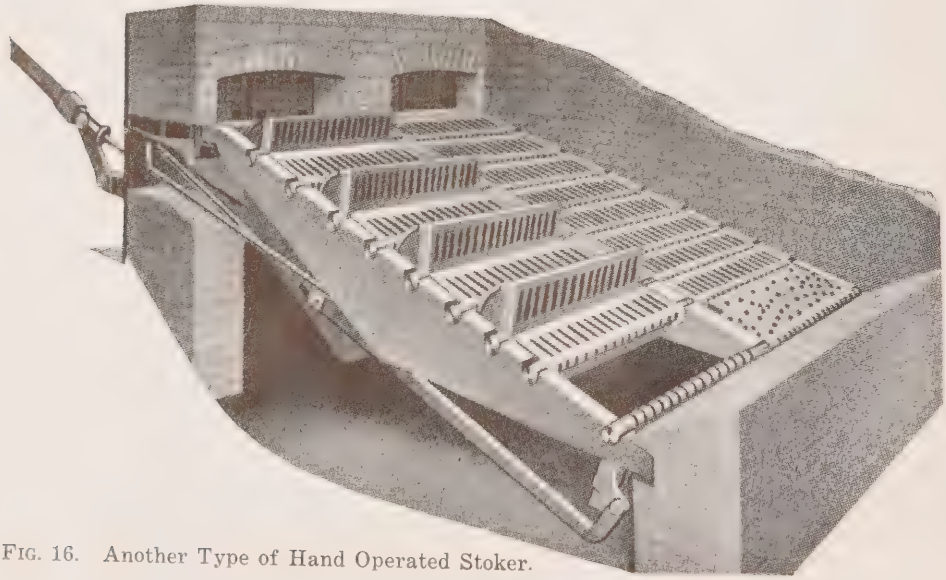

FIG. 16. Another Type of Hand Operated Stoker.

steel pin is cast in the lower end of the shank, which is bent over to lock each top securely in place.

The kicker bars consist of a body portion proper with journals which rock in the journal bearing bars. The journals are extra large and the body portion has a very strong cross section. (See Figures 15 and 16.)

Chain Grate Stokers

Figure 17 is an example of the chain grate stoker. It consists of a hopper which feeds coal on to a slow moving grate. The grate consists of a chain composed of a series of flexible links rotating on two drums, one at each end of the chain.

Over the grate is a brick arch for ignition purposes and to help the burning of the combustible gases.

Chain grate stokers are usually driven by an independent small steam engine or a variable speed motor, and the speed of these can be regulated to the particular quality of coal used and to the load carried by the boiler. Other chain grate stokers are driven by an eccentric and an adjustable arm attached to a line shaft which actuates a ratchet and pawl.

The thickness of the bed of fuel is regulated in all cases by an apron at the front of the boiler.

The principle of operation is that the coal from the hopper drops on the grate and is carried inside the furnace where it cokes. The coke is carried into the furnace and by the time it is entirely consumed it has reached the end of the grates where the remaining ashes drop over the end of the grate into a pit.

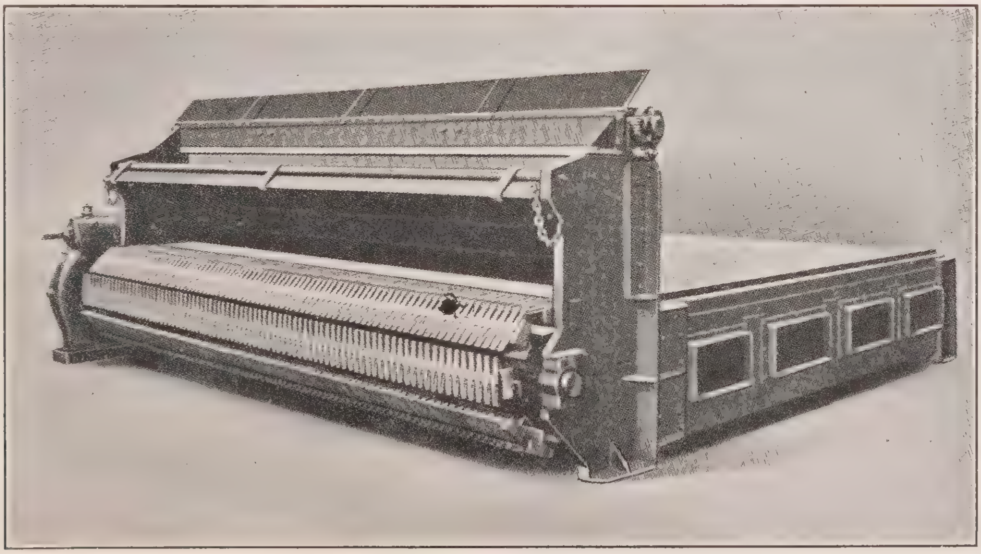

FIG. 17. Harrington Chain Grate Stoker.

In the process the volatile gases, which constitute a large proportion of the heating value of coal, are driven off. In their passage to the boiler tubes and the chimney these gases must pass over the hot incandescent fires, and, assisted by the overhead brick arch, are heated to their ignition point and consumed. Thus no black smoke is allowed to pass up the chimney into the atmosphere.

The air in the natural draught type flows up through both the top and lower chains and reaches the fire in the same manner as in the common stationary grates. In the forced draught type, a number of compartments with individual dampers are placed between the upper and lower chains and connected to a common air duct. Air is forced up through the dampers and upper grate into the coal bed. By means of the separate dampers the different parts of the fire may receive either forced or natural draught, or the air may be shut off entirely, thus creating a means of regulating the amount of air as required by the fuel bed in different sections of the grate.

With different styles of grates and arches, the chain grate stoker can be designed to burn almost any kind of fuel, varying from anthracite screenings and coke breeze to high moisture lignite.

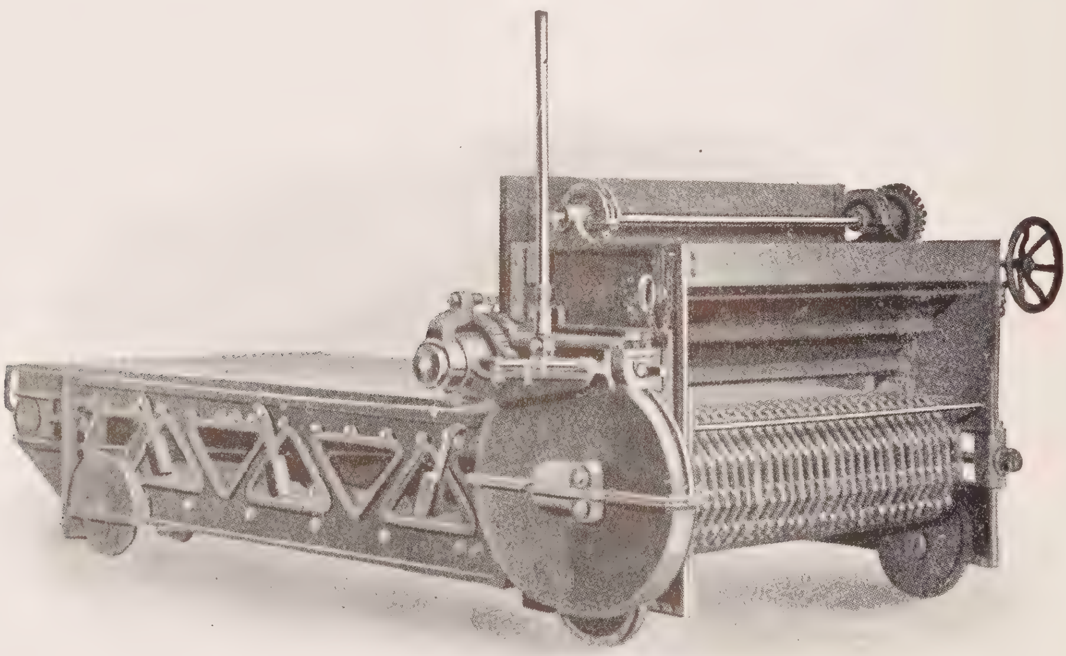

FIG. 18. Babcock-Wilcox & Goldie-McCulloch Chain Grate Stoker.

Chain Grate Stoker Operation

The manufacturers of the Babcock-Wilcox and Goldie-McCulloch chain grate stoker have issued the following instructions relative to the maintenance and operation of this

particular stoker. In a general way we believe that these instructions apply to any make of chain grate stoker.

When commencing to raise steam, the grate should be kept stationary, and where the Stoker is fitted with Air Vanes, these should be closed.

Lift the apron plate, keeping it open by means of the hook provided, and raise the fire door by using the crank handle provided for operating the worm gear which raises and lowers this door.

The fire, in the first instance, should be lighted well to the front—just inside the door—and fed by hand until the arch has become heated; then the fire should be levelled with a rake, the fire door lowered until the pointer indicates three inches on the scale, the apron plate dropped and fastened and the hopper filled with fuel.

The grate can now be set in motion, and should be run first at its lowest speed, viz.: with the figure 1, which is typed on the boss of the handwheel, opposite the arrow cast on the loose chain cover.

After running for a short time, the thickness of the fire and the speed of the grate can be increased to suit the steam requirements. Both the speed and the thickness depend upon the nature of the coal used, the draft available, and the quantity of steam required.

The correct thickness of fire and grate speed for any particular coal can be definitely established by trial.

As a general rule, the thickness of the coal bed should be reduced as the percentage of small coal increases.

With the draught of half-an-inch at the boiler damper, the best results are most likely to be obtained with—

(a) A fire thickness of between two-and-a-half inches and three-and-a-half inches for *small* coal;

(b) A fire thickness of between four inches and five inches for *nut* coal;

Provided always that the driving shaft is running at the standard speed, viz.: fifty revolutions per minute.

The condition of the fire can be examined at any time through the inspection doors provided for this purpose in the side wall of the boiler. If it is seen that the coal is not completely burned out on reaching the ashplates the speed of the grate or depth of fire must be reduced. *It is important that a good bright fire should be always maintained under the arch.*

When the coal reaches the end of the grate it should be wholly consumed and nothing should remain on the ashplates except clinker and ash.

This clinker and ash should be dumped by opening the ash door, but this dumping should only be done at intervals, and a certain proportion of ash or dead clinker should be left on the door, to act as a protection to the metal.

When the Stoker is fitted with air vanes, and when the boiler is working lightly; these should be closed, thus shutting off the air supply to a portion of the grate; but when, with an increase of load on the boiler, it is necessary to run with such a thickness of fire and speed of grate that the fire approaches the ashplates at the rear of the grate, the Air Vanes should be opened.

In the event of it being necessary to work the Stoker for any considerable time with the Air Vanes closed, they should be opened every two or three hours to remove any accumulation of ash.

When shutting down or ceasing to fire for an extended period, close the shutter in the Stoker hopper, keep the Stoker running until the fire is about six inches from the fire doors, then shut the fire doors and stop the grate. The damper at the boiler outlet should be closed, and if Air Vanes are fitted these should also be shut.

Advantage should be taken of any stoppage of this kind to remove any ash and clinker lying on the ash door, by dropping it into the ashpit beneath the Stoker.

When re-starting the fire should be pulled back by a rake; then proceed as described above.

The chain forming the grate should be tightened just sufficiently to keep the top portion of the grate level. The nuts of the tightening screws will be found on the front of each carriage frame.

The clutch actuating the worm is held in position by a spiral spring. This spring is adjusted so that should any undue strain come on the driving gear, the spring will be compressed and the driving clutch released, thus putting the Stoker out of gear, and preventing damage to the mechanism. *The spring when once adjusted must not be tightened, and it is important that the working of the clutch be tested daily, or at each change of firemen during the day.* If the clutch is acting properly, it should be possible to stop the Stoker by means of the ratchet or long spanner held on the end of the worm spindle by one hand. If it is impossible to stop the Stoker in this way the spring controlling the clutch should be eased back until this adjustment is attained.

If during the time the Stoker is working the clutch slips, the cause of the extra friction should be ascertained, but on no account should the spring be unduly compressed.

Should any mishaps occur, the nut on the front end of the clutch spindle should be slackened until the spring is entirely released, care being taken to see that the cone clutch is out of contact with the worm wheel with which it engages. A handle can now be placed on the end of the clutch spindle, and the grate revolved by the hand gear. This will show whether the mishap is due to an obstruction in the grate, or to a fault in the mechanism.

When trying the grate by hand on no account should excessive power be used, otherwise damage to the grate may result.

Important:—In order to ensure the GEAR being always in good working order, it is absolutely essential to keep it thoroughly cleaned and oiled. The gear inside the gear box should be examined periodically, and after each examination should be filled with oil until the latter runs out of the small hole in the gear box.

The Overfeed Stoker

Like the chain grate stoker, the overfeed stoker depends on the overhead brick arch for the ignition of the volatile gases as they are driven off from the green coal.

There are two general types of overfeed stokers, namely: those that feed from the front of the furnace and those that feed from the side. These stokers employ only natural draught. (See Figs. 19, 20 and 21.)

The grates are placed on an incline from the front to the rear of the furnace. In the front feed type the coal feeds from the front down rocking grates to rear and finally the ashes are deposited on a dumping grate. In the side feed or V type stoker the fuel is fed into the magazines by hand or by gravity through chutes and the fuel bed moves down towards the centre of the furnace. Each alternate grate is a moving grate and has a slicing motion, which prevents clinker from forming and keeps the entire fuel bed moving towards the clinker crusher at the bottom. The continuous motion of the vibrating grates and the constant operation of the clinker crusher keep the fire clean at all times. The crushers have a continuous motion, grinding the clinker and depositing the refuse in the ashpit. The combustion is complete and smokeless. The fuel in travelling down the coal magazine to the upper end of the grates, goes through a coking process and the volatile gases are driven off. These gases, which constitute a large portion of the heating value of the fuel, pass over the hot incandescent fires, as mentioned in the case of chain grate stokers, and, assisted by the overhead brick arch are heated to their ignition point.

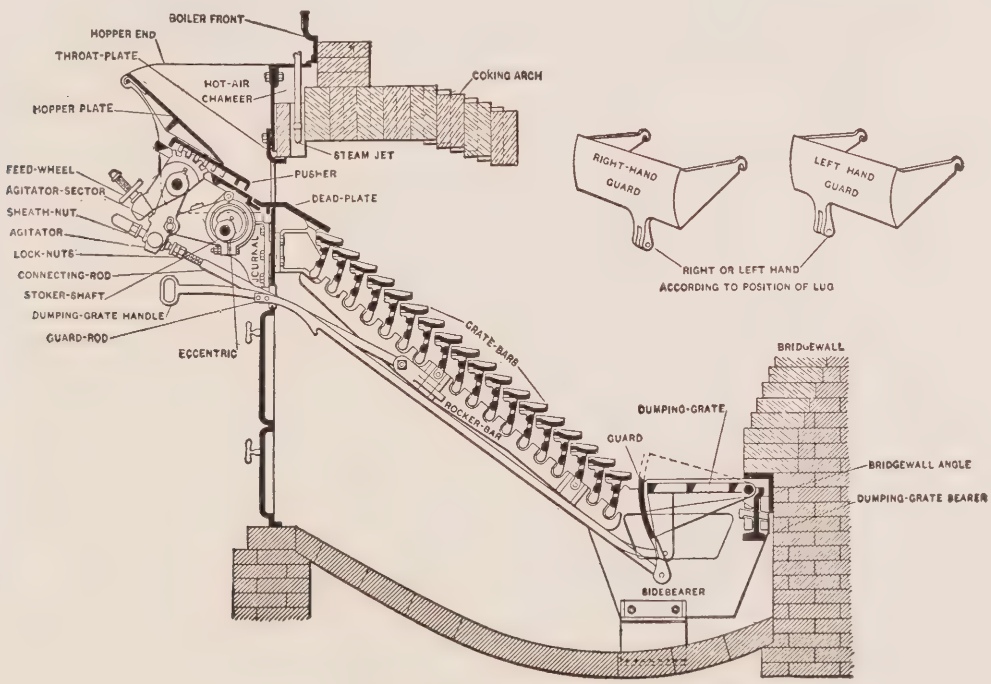

FIG. 19. Roney Stoker.

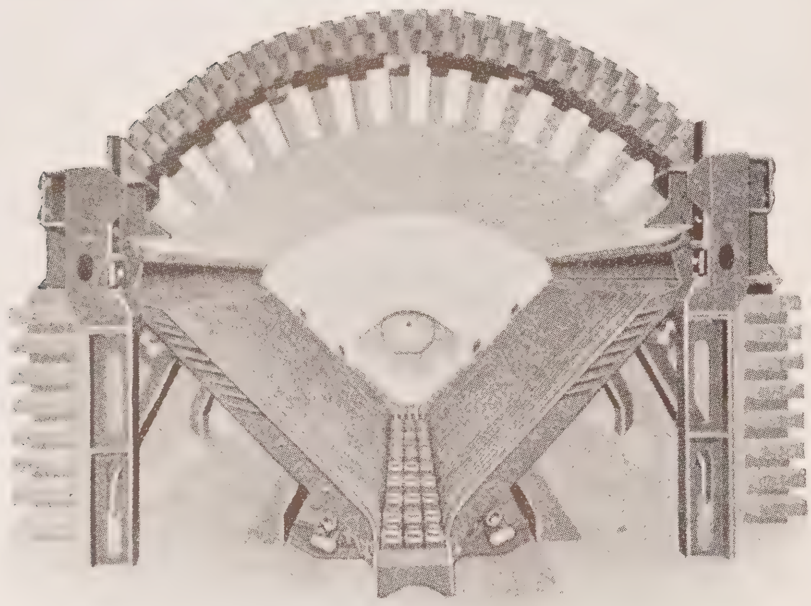

FIG. 20. Detroit Stoker.

Air is drawn in through the stoker fronts, ventilating and cooling the arch, and passes downward into the tuyere openings where it meets and thoroughly mixes with the gases distilled from the coal.

The Underfeed Stoker

The underfeed stoker is of a distinctly different type from the overfeed and does not require the ignition arch. Of necessity, underfeed stokers require forced draught, as the fuel bed is very heavy compared with overfeed stokers or hand firing.

The air is forced through tuyere blocks at the point of distillation of the gases.

Although now built in many different designs the underlying principle of these stokers is the same in all. Fresh coal is pushed in under the fuel bed and gradually forced upward and backward towards the dumping grate. The fuel bed then consists of green coal on the bottom, and above the green coal a layer of coal in the process of coking with a layer of incandescent burning coke on top of all. The volatile gases are driven off in the coking process which takes place in the middle layer of coal, and these must travel through the top layer of coke which is of sufficient heat to ignite the gases. The gases, being mixed with air, are completely consumed, thereby delivering their heat to the furnace and also overcoming the smoke nuisance.

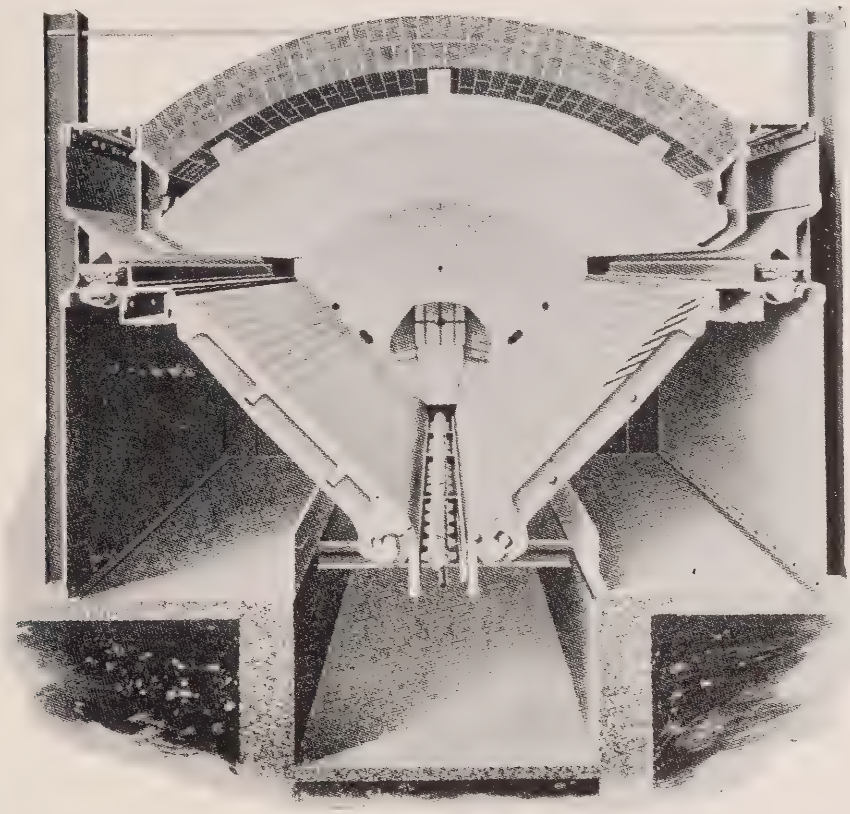

FIG. 21. Murphy Stoker.

Type "E" Stoker

Fig. 22 is a sample of a single retort side dump stoker.

In this stoker the coal is fed by coal-conveying machinery or hand-labor into the stoker hopper, and carried under the fire by means of the reciprocating sliding bottom of the retort which runs the full length of the stoker retort. The coal is delivered uniformly from front to rear by the auxiliary pushers, and as it rises in the retort, is flooded onto the fire bars, which are arranged in pairs, alternately moving and fixed. The moving bars work transversely to the retort, the motion being horizontal, and about one-half inch to one inch in extent.

The movement of the fire bars in addition to carrying the burning fuel to the sides of the furnace also conveys the clinker and ash down and onto the dump trays. The slope of the grate being slight, there is no avalanching of unburned fuel onto the dump trays with resultant bare spots in the fuel bed. The motion of the fire bars at the outward end is such that any clinker present is kept from collecting in large masses. The maximum thickness of fire will not exceed 8 to 12 inches with coking coal and 4 to 8 inches with non-coking

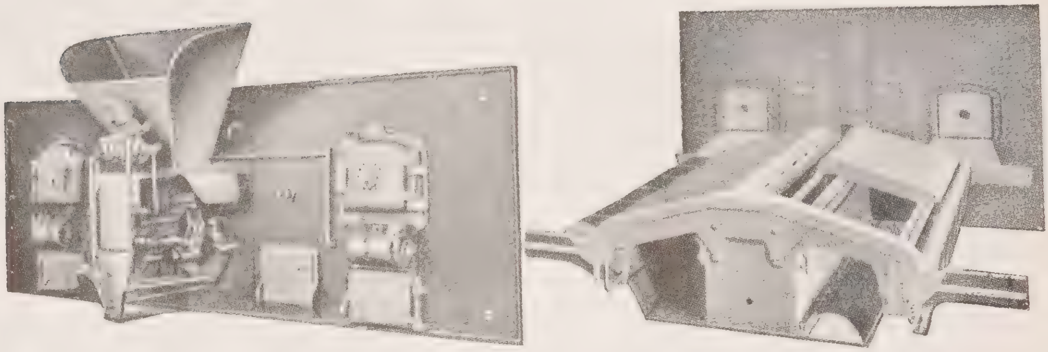

FIG. 22. Type "E" Stoker.

coal. With high ash coal, where the ash is of a low fusing point, any adhesion to the furnace walls may be readily broken off as the dump trays are accessible through the front fire doors of the stoker.

Forced draught is fed through a central wind box under the retort and through the ventilating grate bars.

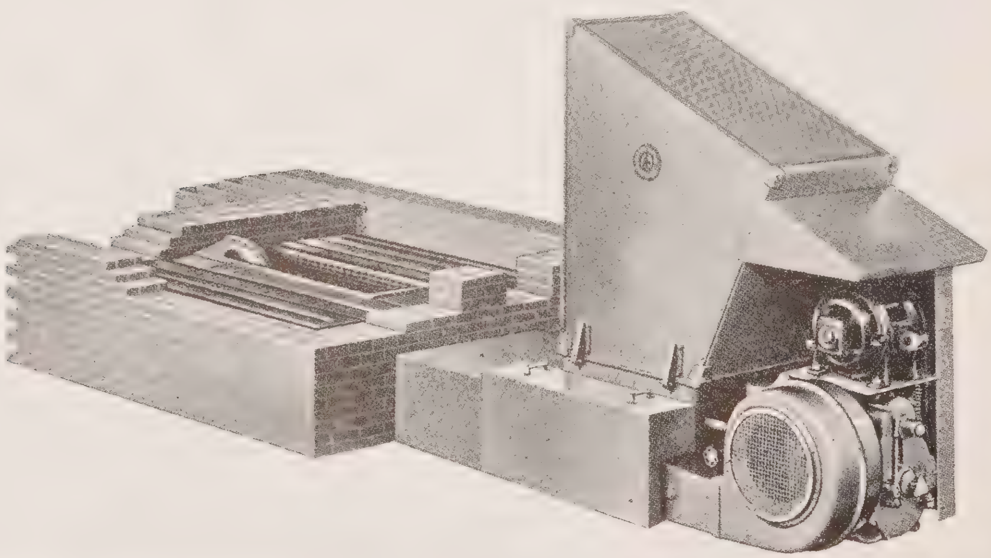

FIG. 23. Iron Fireman—This is a compact, self contained single retort stoker and may be used on furnaces where the boiler does not exceed 300 horse-power. Instead of the ram used on most stokers, the coal is fed by means of a worm. The retort is placed in the centre of the furnace from which the coal overflows on the grates, where it burns as it moves towards the sides. The fan situated at the front of the furnace supplies forced draft beneath the grates.

The Jones "A-C" Underfeed Stoker

This type of stoker consists of a series of retorts which are slightly inclined towards the back. The number of these retorts depends on the size of the boiler. This is known as a multiple retort stoker. (See Figure 24).

Fuel is introduced into the furnace by means of a steam piston which causes a fuel ram to be thrust forward, carrying with it a charge of fuel from the hopper above. The frequency of the charges, and consequently the amount of fuel supplied, is automatically controlled according to the fluctuations in the plant load. Connected to the fuel ram and operating with it are rods to which are connected pusher blocks. The intermittent movement of these pusher blocks causes rearward and upward movement of the fuel bed. This gradual and mechanical progress of the fuel bed guards against avalanching of the fuel bed with resulting holes in the fire and uneven combustion, it prevents the "sliding" of unburned coal into the ash pit and it insures the slow, thorough distillation of volatile so necessary for complete combustion of most steaming coals.

Air is introduced just above the green fuel bed and below the incandescent portion of the fire with the result that volatiles are burned just as soon as they are released, and in combination with coal that has become coked. The result is intense combustion. The fire is practically smokeless.

The air supply is automatically controlled according to the amount of fuel fired. As previously explained the coal feed is in turn governed by the load fluctuation. It will therefore be seen that an even steam pressure is maintained at all times regardless of the variation in steam demand resulting from variations in the plant load. The air supply may be varied at will and retorts can be individually controlled. This provides for forcing for sudden peak loads, and insures an even and effective fire. Overloads of 250% of boiler rating are easily carried for prolonged periods, and peak loads, limited only by the stamina of the settings can be attained in a few minutes.

The gradual slope of the retorts, the manner in which the dead ash is slowly carried to the dump plate and the intermittent slicing of the fire by the pusher rods combine to clean the fire automatically. The tuyeres are specially designed to hold the fuel bed away from the side walls, preventing the formation of clinkers.

The Taylor Stoker

The Taylor stoker operates on the gravity underfeed principle. The coal is fed to the fire from beneath, and works down the grate by gravity aided by mechanical propulsion.

Each stoker contains a number of sloping passages called retorts, by which coal enters from the hopper. The sides of the retorts are formed by iron boxes, 3, covered with perforated cast-iron blocks, 4,4, called tuyeres, through which air is blown from a variable speed fan. (See Fig. 25.)

Under the hopper is a series of slowly reciprocating feeder rams, driven at variable speed by worm gears from the sprocket shaft below. As the coal drops behind the upper

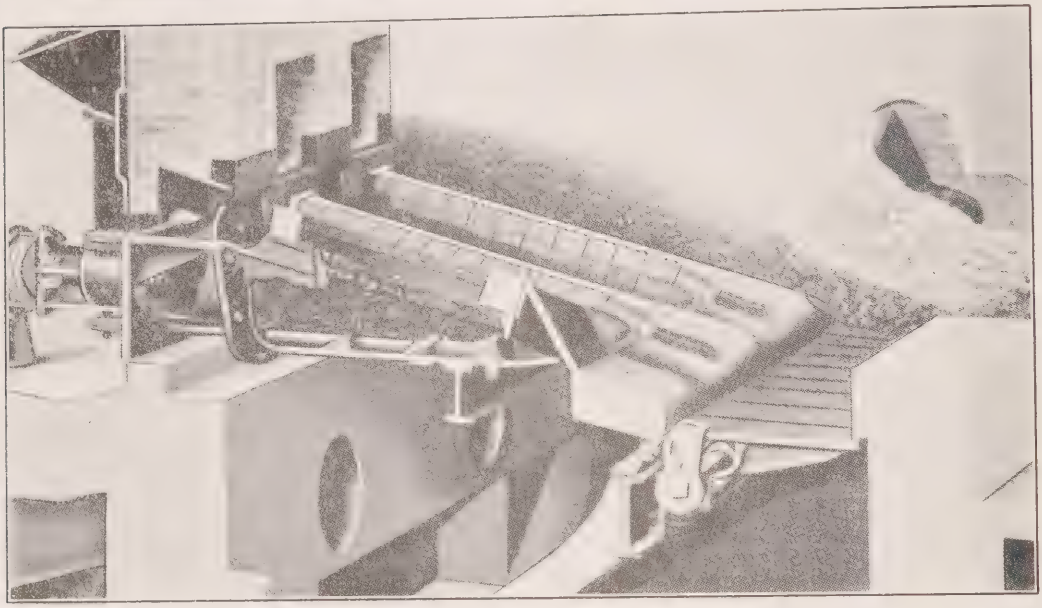

FIG. 24. Jones "A-C" Underfeed Stoker.

rams it is pushed by them into the top of the retorts crowding upward the coal previously introduced.

Part of the green coal moves down the retorts and is pushed into the fire by one (in type AA) or two (in type BA) sets of short-stroke distributing rams, 6,6.

The fuel bed is from two to four feet deep above the tuyeres, and as the green coal works upward and back it is slowly coked by the heat of the fire above. The air and gases, arising through the bed of incandescent coke, are thoroughly mingled and burn with an intense, relatively short, flame.

As the coke is consumed it shrinks and works slowly downward, aided by the movement of the rams underneath. The extension grate, 7, gives additional time for this, and little but hot ash reaches the dump plates, 8.

The power operated dump plate—used in both AA and BA stokers—is hinged, with its swinging edge resting on pawls, which may be rocked by a lever to drop the dump plate. It is controlled by a steam cylinder of sufficient power to raise it quickly and forcibly. It can be raised in order to loosen clinkers adhering to the extension grate, and also to detach slag adhesions if any form on the bridge wall just above the dump plate when the boiler is operated at a high rate. By manipulating a three-way steam valve from the operating stand these adhesions can be knocked loose and dropped and the dump plate restored in a few seconds, without interruption to steaming.

The extension grate sections, 7, are movable, in order to loosen clinkers.

A damper is provided, by which air may be admitted to the extension grate for a short time before dumping, to burn off any combustible remaining in the ash.

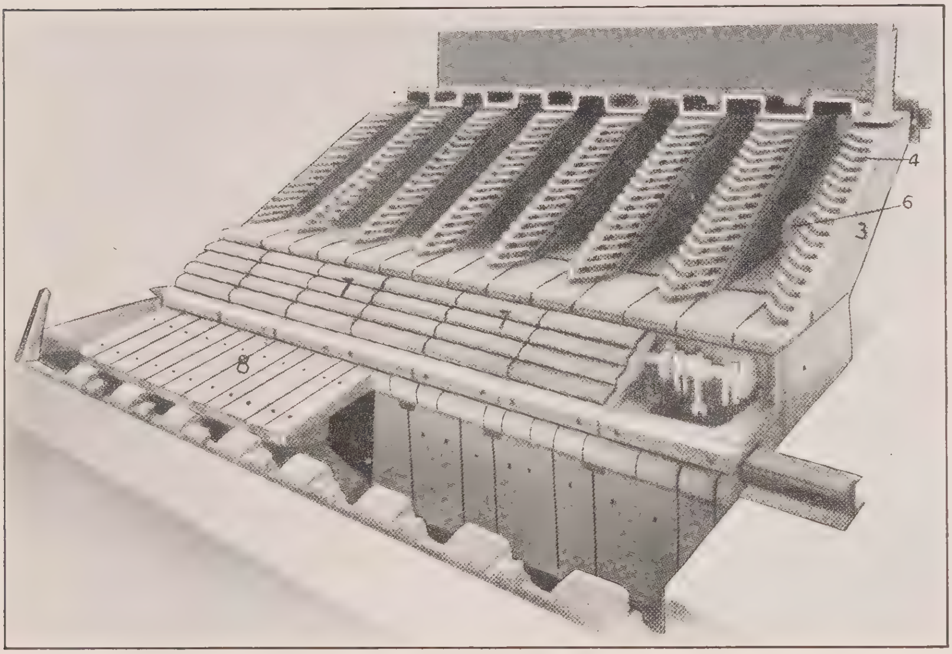

FIG. 25. Taylor Underfeed Stoker.

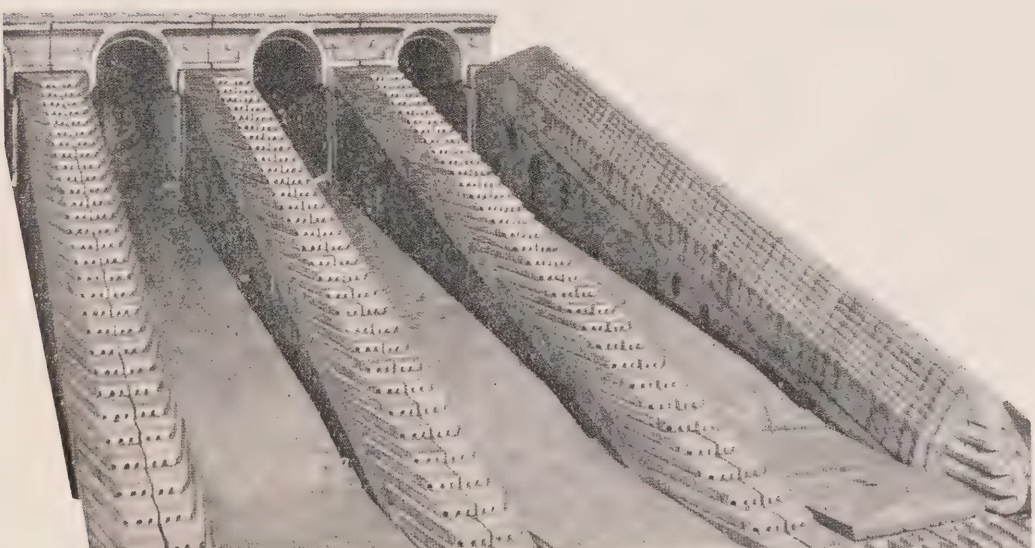

FIG. 26. Riley Underfeed Stoker.

The Riley Stoker

Coal enters the hopper by gravity and is fed into the retorts by means of plungers. The reciprocating movement of the retort sides carrying the air supplying grates distributes the coal evenly over the entire grate surface, and at the same time keeps the fuel bed porous and free from clinkers. They are so effective in accomplishing this that auxiliary pushers are unnecessary. This makes possible an extremely simple design. (See Figure 26.)

The fuel bed is progressively conveyed towards the bridgewall by the reciprocating retort sides. By the time the fuel reaches the overfeed section of the stoker, the volatile matter is consumed and only coke and ash remains. Combustion is then completed over the Riley overfeed or extension grates.

Ash is moved onto the rocker plates which by a combination of horizontal and vertical rocking motions continuously agitate, crush and eject the ash to the ash pit. This feature in the Riley design minimizes the formation of clinker at the rear of the stoker.

Reciprocating retort sides, by keeping the fuel bed open and free from objectionable clinkers and by maintaining a uniform thickness of fuel over the grates, assure proper mixing of air and fuel and high combustion efficiency. They also make possible the efficient handling of variable loads and operation at extremely high rates of combustion.

Westinghouse Stoker

Fig. 28 is a sectional side view of the "New Model" Westinghouse stoker. It consists of downward inclined primary and secondary rams. Forced draught is admitted to tuyeres through the casting supporting the front wall. As in the other types of stoker, the coal as it burns is pushed to the rear on to the dumping grates. Where clinkering coal is burned the dumping grate is replaced by a clinker grinder. Note the high side tuyeres for the purpose of preventing clinkers from adhering to the side walls.

Stoker Operation

The manufacturers of the type E stoker have issued the following instructions relative to the maintenance and operation of this particular stoker. In a general way we believe that these instructions apply to any make of underfeed stoker.

Starting the Fire

1. Remove all caked fuel or clinker from retort. Fill the stoker supply hopper with coal making sure that the coal to be fed is of the proper size and is free from foreign material.

2. Start the stoker in the same manner as described above and feed in sufficient coal to cover about 75 per cent of the grate surface. Then stop the stoker.

3. Build a wood fire over the full length of the retort, or as an alternate method spread live coals over the full length of the retort.

4. After the coal in the retort ignites, start the forced draft fan and crack the forced

draft damper controlling the air to the main air chamber. When the coal over the entire retort is burning, slowly increase the air pressure in the main air chamber.

5. Adjust the uptake damper to maintain a draft in the furnace of between –.05 and –.15 of an inch of water.

6. Now start the stoker and operate it very slowly until ignition is strong. At the start, adjust the speed of the stoker to about one stroke per minute.

7. When ignition has been obtained over the entire grate surface, the stoker speed and air pressure in the main air chamber may be increased to handle whatever steaming load is required of the boiler.

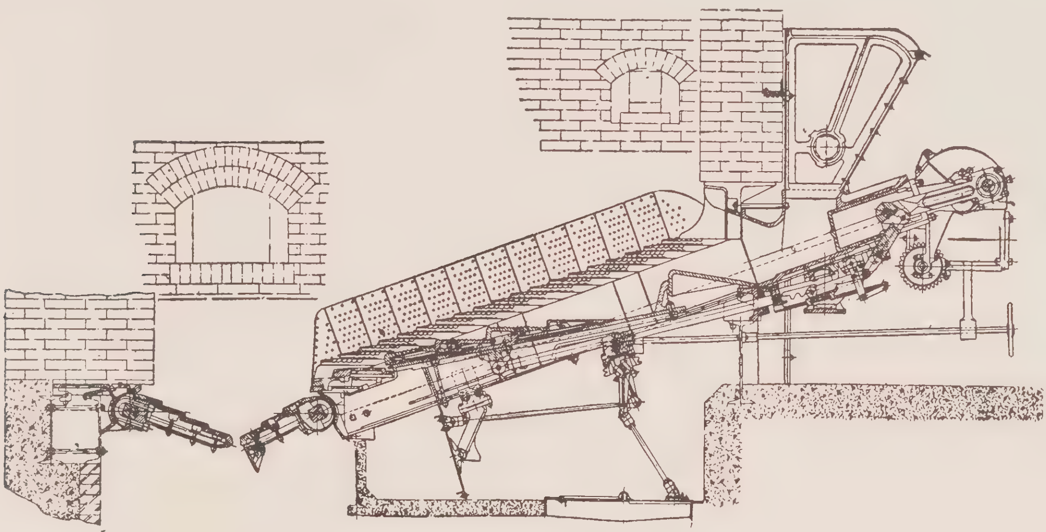

FIG. 28. Westinghouse Underfeed Stoker.

Operating

Keep the fuel bed just thick enough to maintain the desired rating. In general good results can be obtained with fires from 6 to 10 inches thick above the top of the retort, tapering down to about three inches at the ends of the grate bars. When burning coking coal at very low rates a slightly heavier fire may need to be maintained.

Over the operating range of ratings the pressure in the main air chamber will need to vary between 2″ and 6″. The air pressure in the auxiliary air chamber will normally be about one-half that in the main air chamber, due to the drop in pressure of the air in passing through the hollow grate bars. The air control should be regulated so as to burn all of must learn to adjust the air supply by the indications of the CO_2 recorder or steam flow-air flow meter and by intelligent observations of the fire. The amount of "over fire air" admitted through the air ports in the walls at different ratings must be determined by the coal on the grate by the time it reaches the dump trays and at the same time to not use such an excessive amount of air as to impair the efficiency by a high stack loss. The fireman

experience. "Over fire air" is particularly effective in reducing smoke and preventing the formation of CO. Although sufficient "over fire air" should be introduced into the furnace to keep these at a minimum, care should be taken that enough air is passed through the fuel bed to completely burn out all fixed carbon of the fuel.

If automatic regulation is used, too much dependence should not be placed upon the regulator. It is only a mechanical device and cannot meet every condition encountered in plant operation. Therefore, the fireman should keep a constant watch on the condition of the fire and if necessary vary the settings of the coal feed and air flow to meet the immediate requirements.

FIG. 27. Clinker Grinder.

The forced draft fan should run at nearly uniform speed for the load being carried and this speed should not vary enough to cause wide fluctuations in the air pressures, which in turn would produce alternate intense or dull fires. Poor regulation of air pressure in the main air chamber will result in inefficient combustion and even burned grate bars. The rear boiler damper should at all times be adjusted to maintain a draft in the furnace of between –.05 and –.15 of an inch of water. This condition will result in a minimum leakage of air into the furnace through the access doors and other points over the fire.

Never entirely shut off the forced draft when carrying a hot fire. This may cause overheating and burning of the fire bars or other stoker parts.

Except in an emergency, never operate the stoker with no forced draft. In case of an emergency when it becomes absolutely necessary to operate with natural draft, take the air through the regular air duct.

Never slice the fire as it is done when hand firing, by pushing a bar under the fire and raising it through the fuel bed. It should not be necessary to touch any part of the fire above the grate with a slice bar or hook, except when there are large holes in the fire. In this case smooth over with a light "T" bar or the back of a rake.

Cleaning Fires with Dump Trays

The frequency of cleaning the fires will depend upon the amount of coal being burned. The average period between cleanings should be about two hours. When the ash begins to accumulate on the grate bars from 4 to 6 inches from their lower ends, the fire is ready to be cleaned. Observation of this ash accumulation is a good way of judging when the fire must be cleaned. Clinkers extending back on the fire bars over six inches indicate that the stoker has been operated too long without cleaning.

The general procedure is as follows:

1. Slow down the stoker for 10 or 15 minutes previous to dumping ashes in order to burn down the fire.

2. If there is much unburned coal on the dump trays, open the slide damper in the stoker casing which divides the auxiliary air chamber from the space beneath the dump trays. This will allow forced draft air to pass into the ash pit and through the dump trays, thus hastening the burning out of the unburned coal.

   Break up any clinkers on the dump trays by using a slice bar through the peep holes in the front fire doors.

3. When the fire is well burned down, stop the stoker.

4. Close the slide dampers admitting air to the ash pit. Lower the dump trays. Do not touch or disturb that part of the fuel bed over the grate bars. Never try to clean clinkers off the grate bars. Only dump the clinkers that are on the dump trays.

5. If there are any clinkers adhering to the side walls above the dump trays, remove them with a slice bar.

6. Raise the dump trays and wet down the ashes in the pit.

7. After cleaning, start the stoker and increase the coal feed until the fuel bed has reached the proper thickness. Do not pull fuel down on dump trays after cleaning the fire. Let the stoker work the fuel down. Pulling live fuel down on the dump trays will result in burning the dump trays and toe ends of the grate bars. If the stoker is adjusted to run six or seven strokes per minute it is only a question of three or four minutes before a protective covering of semi-live fuel is on the dump trays.

8. Ashes in the dump pits should be removed immediately.

Cleaning Fires with Grinders

The frequency of cleaning the fires will depend upon the amount of coal being burned. Observation of ash accumulation is a good method of judging when fires should be cleaned.

The general procedure is as follows:

1. If there is any unburned coal on the grinders it is advisable to open the auxiliary dampers that supply air to the grinders sufficiently to consume any unburned coke.

2. When the fire appears dull, the grinders should be operated just enough to avoid an excess.

3. When this is no longer effective in brightening up the fire, it is an indication that there is an accumulation of clinker which should be removed. This may occur when burning a fuel with a low fusion temperature ash. If the clinker cannot be broken up with a slice bar so that it will pass through the grinder, it may be necessary to remove the clinker through the fire door. Normally this clinker can be disposed of through the grinder. If there are any clinkers adhering to the side walls they

should be removed with a slice bar at the same time. Enough ash should remain on the grinder at all times to protect it from incandescent fuel.

4. Make sure that no live fuel is allowed to remain in the ash pit. Ashes should be wet down and should not be allowed to accumulate in the pit.
5. Do not pull the fuel down on the grinder after cleaning the fire. Let the stoker work the fuel down. Holes should not be permitted to form over the grinders. If for any reason a hole is formed it should be filled in immediately with a hook.

Removing Clinkers

Side wall clinkers should be removed by means of a slice bar whenever ashes are dumped. Bridge wall clinkers which form over the rear end of the retort should be cleaned off every 24 hours. These can be removed by prying them off with a long bar having a flat chisel edge. Front wall clinkers can be cleaned off with an "L" shaped bar which will reach from the fire door to the centre of the furnace.

Removing Siftings

The auxiliary air chambers should be cleaned once every shift. One large clean out door is provided on each side for this purpose. The main air chamber should be cleaned of siftings once a day. On some stokers a clean out door is provided under the feed box at the front of the stoker. On other stokers the siftings can be removed by way of the air duct. Failure to remove siftings may result in the siftings piling up high enough to become ignited and to cause serious burning of some of the stoker parts.

Banking

Do not dump the ashes previous to banking the fire, as the ash protects the dump trays and grates during the banking period.

1. Run the stoker very slowly and leave the full air blast on until the fire is well burned down.
2. With the sliding bottom in its inward position, stop the stoker and continue burning down the fuel bed until the coal on the grates is burned back nearly to the retort.
3. Entirely shut off all forced draft to the stoker.
4. Start the stoker and feed in enough coal for the duration of the bank. Then stop the stoker.
5. Close tightly the boiler outlet damper and all ash pit fire doors. A tight boiler damper is essential for holding a banked fire.

Caution:—Never allow a banked fire to burn down into the retort as it will burn off the end of the grate bars and lugs which hold the stationary grates to the retort sides. There should be green coal in the retort at all times while the stoker is on bank. If the coal should burn back to the top of the retort, start the stoker and feed in enough coal to

move the hot zone away from the retort. It is advisable to run the stoker a few strokes every hour throughout the banking period so that the hot zone will be kept well away from the retort.

Starting Stoker after Banking

To resume operation after a banking period:

1. Gradually increase the forced draft pressure.
2. Start the stoker.
3. As the fire brightens up, clean it as described above.
4. After the proper fuel bed has been obtained, adjust the stoker speed and air flow for the rating to be carried.

Taking Stoker from Service

The following is the general procedure to be carried out in removing the stoker from service:

1. Stop feeding coal to the supply hopper.
2. Operate the stoker slowly until the hopper is empty and the fuel bed on the grates is well burned down.
3. Fill the supply hopper with ashes and feed into the retort. Repeat this two or three times. The ashes will force the coal from the retort and prevent burning of the coal in the retort.
4. Shut off the air.
5. Keep all ash pit doors and fire doors closed and allow the furnace and all stoker parts to cool down very slowly.

Periodic Inspections

Whenever the boiler is removed from service for repairs or cleaning, the stoker should be given a general overhauling and cleaning.

1. All grate bars should be removed and thoroughly cleaned of siftings and ash which may accumulate on the inside. When removing the bars keep them in the proper order so that they may be replaced in their former positions. In replacing grate bars always commence at the rear of the stoker next to the bridge wall, with a moving bar and alternate with a stationary bar. Always finish at the front of the stoker with a moving bar. It is sometimes necessary to place two moving bars together to accomplish this, in which case they should both be placed at the front of the stoker. After being in service for a long period, the motion is reduced and it is advisable to place two moving bars at the rear of the stoker next to transverse bar and alternate with stationary bars as before, ending up with a moving bar at the front of the stoker. Care should be taken that there is at least $1\frac{1}{2}''$ clearance be-

tween the adjusting bars and the grate bars when the spring is removed to allow for expansion. To accomplish this it is sometimes necessary to use filler bars. If necessary, replace any burned grate bars with new ones.

2. Thoroughly clean the main air chamber, auxiliary air chamber and forced draft duct of all accumulations of siftings.
3. The retort should be thoroughly cleaned out and the auxiliary pushers should be inspected for wear. If necessary replace any extremely worn pushers.
4. Go over the entire stoker and tighten up all bolts and nuts, making sure that all are tight. Parts sometimes become loose after the stoker has been in operation some time.
5. Remove all slag and clinker adhering to the side, front or bridge walls. Care should be taken not to injure the brickwork when removing slag formations.
6. If any brickwork is badly eroded, see that it is repaired before putting the unit back in service.
7. Go over the entire operating mechanism of the stoker, making sure that all dirt and coal has been cleaned out of the teeth of the rocker bar gears and all other moving parts. See that they are well greased. If the stoker has a helix rocker bar drive, make sure that it operates freely and that the helices are well lubricated.
8. If the stoker is steam driven, inspect the packing glands of the operating valve and the main stoker cylinder. If necessary, renew the packing at these points.

Maintenance of Auxiliary Equipment

The operating efficiency of the fan will depend to a great extent upon the condition of the blades of the fan wheels. Due to conditions under which the fans usually operate, dust will gradually accumulate on the blades and form a scale which will lower the efficiency of the blades considerably. Accumulations and wear may cause the fan wheel to be thrown out of balance. The fan wheels should be cleaned at intervals. If the fan shows any signs of being out of balance, shut it down immediately, inspect it and rebalance it.

If the forced draft fan is turbine driven, the turbine should at all times be operated in accordance with instructions furnished by the turbine manufacturer. Special care should be given to the selection of oil, as poor lubrication is a most frequent cause of trouble. If the forced draft fan is engine driven or motor driven, all operating instructions and maintenance recommendations made by the manufacturer should be strictly adhered to, and with the electric driven stoker, the care and lubrication of the motor should be governed by the manufacturer's recommendations.

Operation of the Jones Stoker

1. The Jones Stoker is to be had in the following Drives:

   (*a*) *Steam:* Steam Driven Stoker with Turbine, Engine or Motor Driven Forced Draft Fan.

(*b*) *Oil Hydraulic:* The Jones Hydraulic Drive provides an extremely simple, ruggedly constructed electrically driven stoker of the plunger type. The hydraulic drive embodies all of the advantages of the steam drive for an installation where steam is generated at a pressure too low for operation of the stoker with steam. The Jones Hydraulic Drive has been designed so as to actuate the plunger with the same quick thrust as obtained with the steam drive. This is a very important feature as the quick thrust of the coal plunger has proven the most effective means of maintaining the fire in condition for the most efficient burning of the coal.

The Jones Hydraulic Drive consists of an oil reservoir tank upon which is mounted a compact motor driven oil pump and forced draft fan unit, the stoker hydraulic cylinder, piston and coal plunger and an especially designed valve for controlling the operation and speed of the coal plunger. This valve is so designed as to cause the plunger to move with a quick out- and in-stroke regardless of the rate of coal feed. Control of the amount of coal fed by the stoker being obtained by having the plunger pause at the completion of the in-stroke for variable periods of time.

The pump and forced draft unit is installed at any convenient location in the boiler room near the stoker. Where more than one stoker is installed, this unit is built sufficiently large to take care of the battery of stokers. Oil, for operating the stoker piston, is supplied under pressure by the oil pump through piping connections and is discharged back to the oil reservoir.

(*c*) *Mechanical:* Consisting of a spur gear reduction drive with gears operating at a constant speed. The rate of coal feed is varied by means of an intermittent plunger and the number of strokes of the plunger is regulated by means of a unique timing device. This drive provides a quick positive thrust of the plunger. The driving motor is constant speed, while automatic regulation of the coal is obtained without the use of complicated electrical regulating devices.

2. *Starting Fires:*

(*a*) With steam to operate stoker, fill retort by means of the ram so that tuyere blocks are covered with green coal. Scatter fire along each side and centre of retort, on top of the green coal; start blower, slowly increasing speed as the fire builds up.

(*b*) Without steam to operate stoker, shovel coal through fire doors till retort is full and tuyere blocks are completely covered. Build wood fire on top of green coal, leaving fire doors open for draught. Fire with wood until sufficient steam has been raised to operate the blower; start blower slowly, increasing the speed as fire builds up. Then discontinue the wood; fire by hand through the fire doors in usual manner until sufficient steam pressure is obtained to operate the ram; from 30 to 40 pounds is usually sufficient. After blower is started steam can be raised in a few minutes.

(*c*) With the oil hydraulic stoker, build fire up by starting the power unit and feeding coal into retort until over the tuyere three or four inches, then build a wood fire and open air control slightly, and as soon as coal ignites and gets well under way, open the coal feed valve.

3. *Operation of Automatic Control for Steam Stoker:*

Before running automatic attachment with belt always turn steam on all automatic valves and give valve chamber time to expand before attempting to place same in operation, thus preventing binding due to unequal expansion.

Always keep the automatic valves well supplied with oil.

Keep oil reservoir in valve well stem supplied with oil.

Operation of Automatic Control for Oil Hydraulic or Mechanical Stoker:

(*a*) The Standard type of stop and start control is sometimes used to start and stop stoker and fan in maintaining desired boiler steam pressure.

(*b*) When accurate proportioning of coal feed and air supply is called for, we use our Full Floating Control System, which controls the coal feed to the boiler and operates a Louvre damper on the fan exhaust admitting the correct amount of air to the fuel bed for the amount of coal being fed.

4. *Coal Supply:*

Should be continuous and sufficient to maintain a heavy fire from 14 inches to 24 inches deep over retort.

To increase supply of coal set index trigger to a higher number; never shovel coal on top of fire.

To decrease supply of coal set index trigger to a lower number.

To cut off supply of coal set index trigger at zero.

The Cole attachment, in connection with the regulating valve controlling speed of engine, automatically increases the supply of fuel and air with the demand for steam. A little practice will enable the operator to set the adjustable index trigger so as to maintain the required depth of fire.

To burn down fires decrease supply of coal, but do not entirely cut off the supply.

To build up fires increase supply of coal. It is sometimes desirable on starting fires, or after cleaning, to build up fires quickly, which may be done by operating the valve with crank furnished for the purpose; one revolution of the valve giving one charge of coal.

In operating valve by hand, always turn it to the right when primary valve is on left hand side as you face the attachment, and vice versa when primary valve is on the right hand side.

In thus operating valve by hand give ram sufficient time to complete forward stroke before withdrawing it for another charge. Repeated short strokes of ram tend to pack coal so as to necessitate removal of coal from ram case.

5. *Cleaning Fires:*

Fires must be cleaned when accumulation of non-combustible matter in the furnace interferes with combustion. The greater portion of refuse forms a vitrified clinker on dead plates. Lift clinker from dead plate with slice bar, and remove only the clinker with hook. Never clean so as to expose dead plates to intense heat of fires. Let the ash and unconsumed coke remain on side plates. Clean on dead plates and top of tuyere blocks only. The retort will keep itself clean. Shut off forced draught when cleaning. Do not burn the fire down too thin before cleaning.

With the side dumping grate type, burn the coal down on the dumping grates then dump.

Be sure to keep clinker formation free from particularly the rear of the retort at the bridge wall.

6. *Cleaning Ash Pit:*

This should be done as often as required, and no large amount of ash should remain under stoker dumps.

7. *Distribution of Coal:*

With the proper stroke of the pusher rod a constant depth of fuel will be maintained throughout the length of the retort and the entire body of fuel will have an upward as well as an outward movement. The correct distribution of fuel for the furnace is governed also by the position of the shoes on the push rod. The delivery of the coal may be readily increased at the front end of the retort by decreasing the stroke of the pusher rod, and vice versa. To decrease the stroke of the pusher rod move mid bolt in pusher rod strap one or two holes nearer retort end of strap and vice versa. In the case of the small series of Jones stokers, the shoes on the push rod are adjusted properly when the stoker is erected.

8. *Banking Fires:*

To bank the fire close off air from fan and have ram feed sufficient coal into retort to cover the tuyeres then reduce the stack damper. In the case of the steam stoker the valves on the automatic controls are usually shut. In the case of the oil hydraulic stoker, when using a stop and start control and operating a heating load, the stoker-switch control brings the stoker and fan into operation for about one to two minutes to the hour over a long period when the stoker would otherwise be out of operation, and thus maintains a fire which will respond quickly to the demand for steam when the load again comes on. The control switch may otherwise be shut off and a banked fire maintained as above outlined. In breaking the bank, close off the coal feed and open up air from fan until fire is well under way, and after steam pressure is up, clean the fire.

9. *General:*

If the ram of the steam driven stoker fails to complete its forward stroke, shut off

coal feed, bring ram back by operating control valve with crank; shut off steam supply to stoker; close both ports of automatic valve; set index trigger at zero; let steam out of cylinder then remove obstacle.

Avoid slicing or raking fire, except at time of cleaning the fires.

In carrying a "Peaky" process load on boiler, carry a medium fire of 10 to 14 inches deep over retort using free burning non-coking coal.

When stack draft is insufficient to carry products of combustion to heating surface of boilers or when too much forced draft is carried, some gas is likely to back out through hopper and this may also be occasioned by carrying the fire too low or by allowing a clinker to remain immediately over the front end of the retort. By reducing air supply from forced draft fan the trouble will be overcome unless stack draft is insufficient, in which event the only remedy is to provide additional draft.

10. *Adjustments:*

Examine periodically bolts on pusher rod connection, keeping same in proper condition. Oil cylinder of steam stoker frequently. Keep stuffing box properly packed.

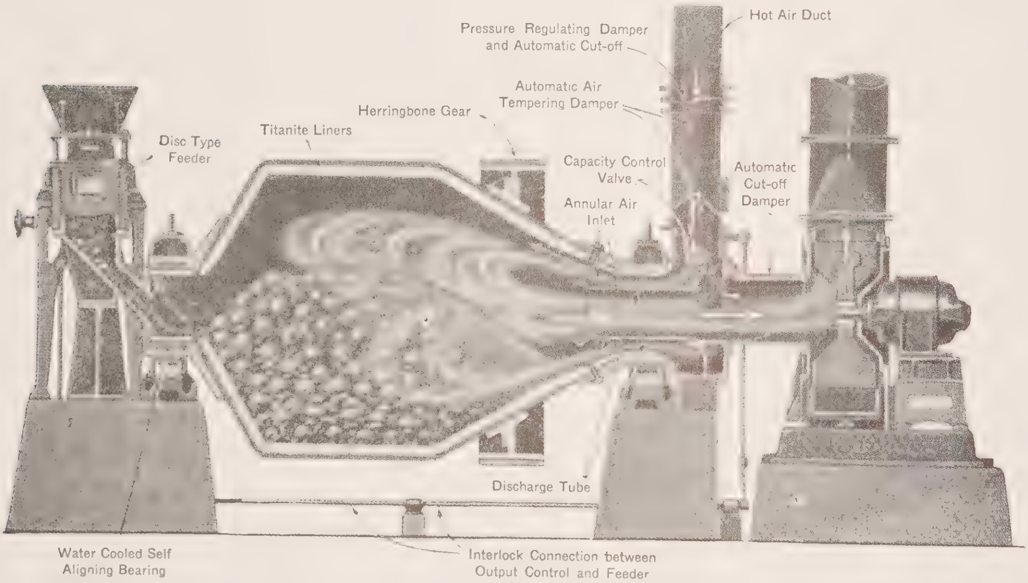

FIG. 29. Harding Ball Pulverizing Coal Mill.

Powdered Fuel

A powdered fuel furnace is one in which coal ground to a fine powder, is burned. This coal being mixed with air is fed into the furnace and is, like oil and gas, burned while floating in the air and before it settles, and therefore no grates are required. The ease of contact of the air with the fine particles of coal tend to make combustion more complete than when lump coal is used and to create a higher furnace temperature. Much of the ash in the form of very fine particles is carried with the flue gas up the chimney to the atmosphere, but as it contains little or no soot, it is not as objectionable as black smoke.

Powdered fuel is prepared by means of pulverizers. There are a number of different types of these on the market. Fig. 29 shows a Hardinge ball mill. It contains a conical shaped container which is made to revolve. Inside the container are steel balls. Coal is fed into the container and as it revolves the coal and balls are tumbled about together with the result that the coal is reduced to dust. This coal dust is drawn off from the container by means of a hot air draft.

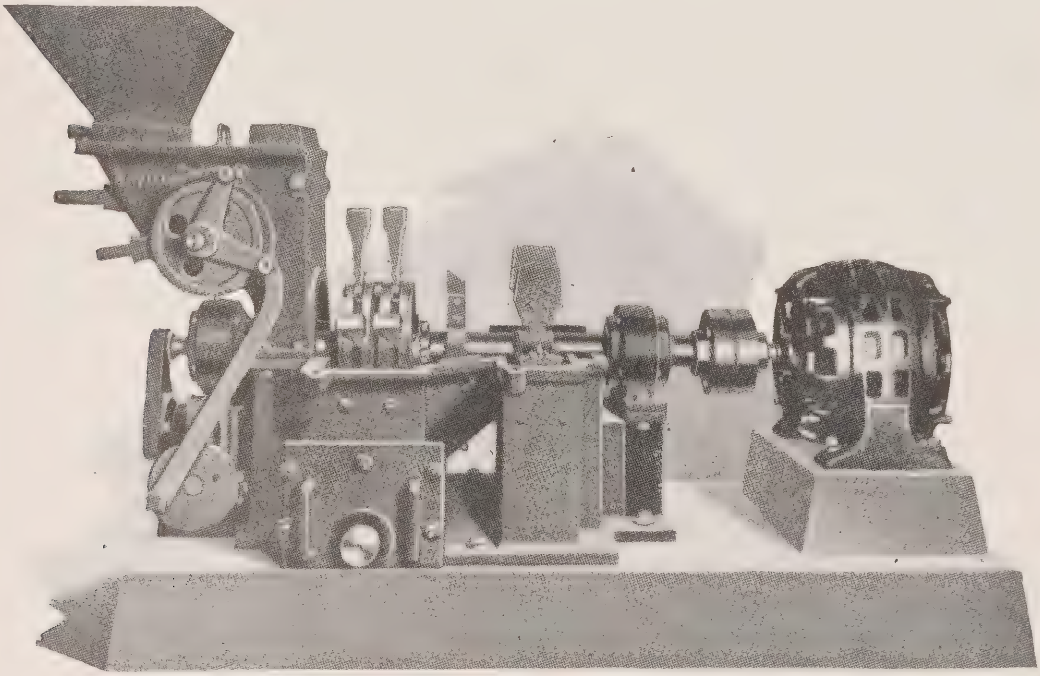

FIG. 30. Impact Unit Type Pulverizer.

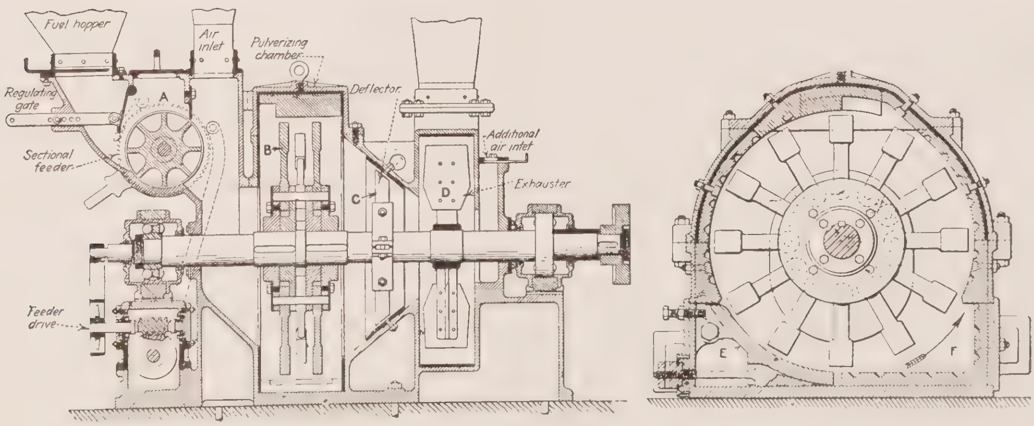

FIG. 30A. Cross Section of Impact Unit Type Pulverizer.

Figure 30 shows a different type, in which the pulverizing of the coal is accomplished by the hammer action of revolving paddles. The mill obtains its coal direct from the raw coal bunker, or from a dryer, if a high moisture coal, necessitating drying, is being used. It is equipped with an automatic device which permits the volume of coal entering the mill to be increased or diminished while the mill is in operation. This control can be operated either by hand or by automatic regulation in accordance with the steam demand.

Swing hammers are pivoted to the rotors instead of the commonly used stationary beater blades. These pivoted hammers are advantageous when tramp iron or other foreign material enters the mill with the coal; not being rigidly connected to the rotor, they swing back when they encounter any foreign material, thereby preventing damage to the mill. The tramp iron or foreign material that enters the mill is driven into a pocket at the bottom of the pulverizing chamber, from which it can be removed periodically as desired through access doors provided for this purpose.

At one end of the rotor shaft, a fan is mounted which "sucks" the coal as it is pulverized through the pulverizing and fineness regulating chambers, and then blows the mixture of air and pulverized coal through the feed pipe and burners into the furnace.

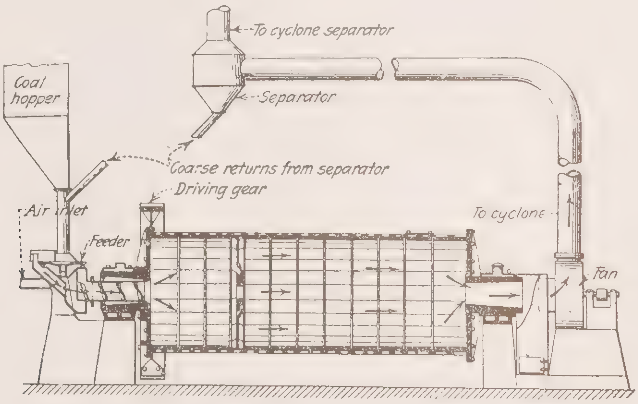

FIG. 31. Air Separator Type of Tube Mill Pulverizer.

Pulverized Coal Under Boilers (Kent)

For boiler operation, 96% of the pulverized coal should pass a 100-mesh sieve and 85% through a 200-mesh sieve. A smaller percentage than 80% through the 200-mesh sieve will cause accumulations to be built up in the combustion chamber. The size of the combustion chamber should be approximately 50 cu. ft. per lb. of coal burned per minute, or approximately $2\frac{1}{2}$ cu. ft. per boiler horsepower developed. The combustion chamber should be designed to handle the maximum load which may come on the boiler, for the reason that if the boiler furnace is operated beyond its designed capacity, the increased quantities of coal and air will impinge on the brickwork and destroy it rapidly, due to the lack of combustion space. Operating the furnace at a lower capacity than that for which it was designed will not materially affect the efficiency. The pulverized coal should be admitted to the furnace at as low a pressure as will carry the coal in suspension, or about

one-half ounce per square inch at the nozzle. The damper regulation should be such that practically a balanced draft exists inside the combustion chamber with a slight vacuum in the first pass, the draft at the damper being from 0.1 to 0.15 in. This small draft enables boilers to be operated with pulverized coal with stacks not over 35 feet high, it is essential that the tubes of the boiler should be blown off at least every six hours, otherwise the material depositing on the tubes will accumulate rapidly and fuse.

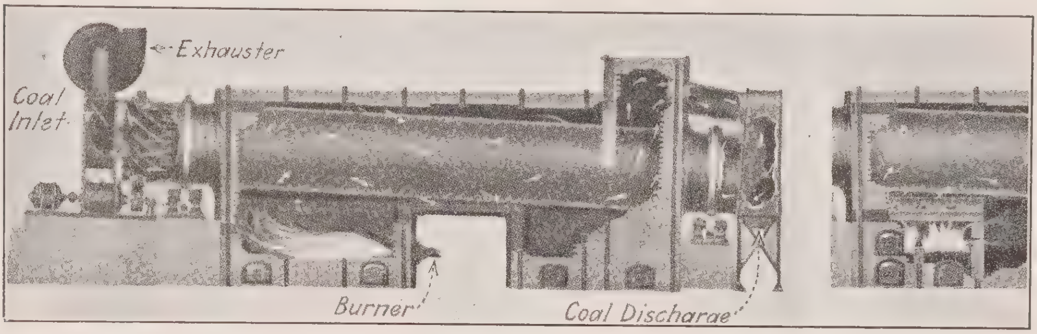

FIG. 32. Pulverized Fuel Rotary Drier.

Effect of Moisture

Coal containing less than 2% moisture will work satisfactorily in a pulverized form but if the percentage of moisture runs above this amount trouble is experienced in handling the coal.

When coal contains more than 2% moisture it is necessary to dry it. This is usually done by passing the coal through a revolving dry kiln or rotary drier or through a stationary waste-heat drier.

There are various types of these driers in geneal use but it should serve our purpose if we describe two only.

The rotary drier shown in Fig. 32 consists of a shell mounted on bearings. It will be observed that the shell is inclined and the amount of the slope varies generally between half and three-quarters of an inch to the foot. The drum is made to revolve slowly. While it revolves the gases from an independent furnace are brought in contact with the outside and thence back through the inside in the opposite direction to which the coal is travelling. Thus the moisture in the coal is carried away.

The waste-heat drier shown in Fig. 33 is built up of unit sections, one above the other, each unit having a series of gas ports. The coal is fed in at the top and moves by gravity to the bottom. The drying of the coal is effected by the direct contact of the hot gases with the coal.

There are two general methods of handling powdered fuel. One method is to store the fuel in bins and use it as required. The other is to grind the coal as needed and blow it direct into the furnace. With the second method, what is known as the "Unit" pulverizer is set in front of the boiler and fed from overhead bins, discharging direct to the furnace without any pre-drying of the coal.

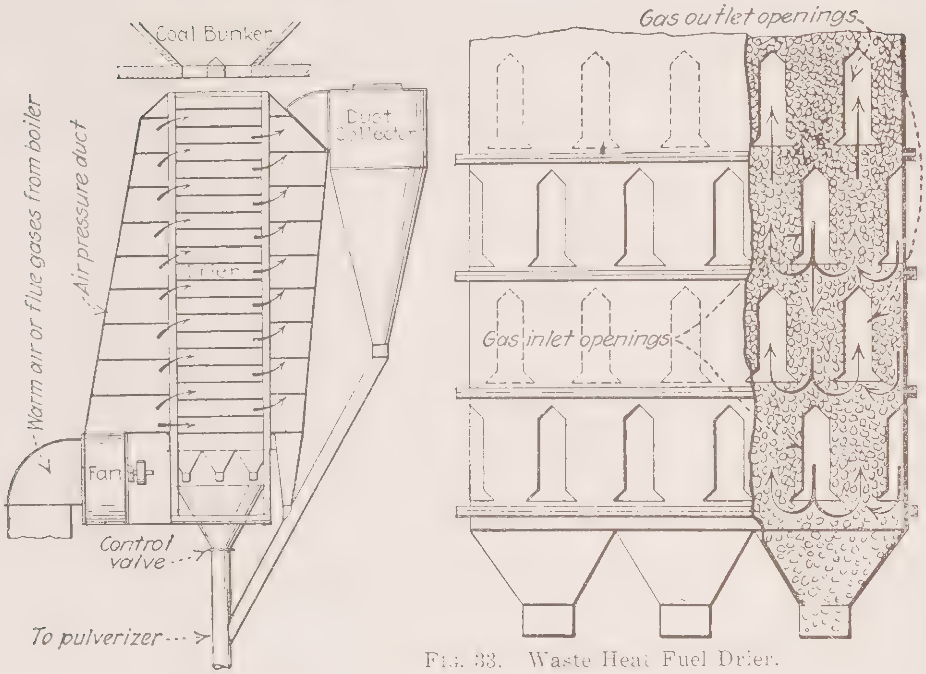

Fig. 33. Waste Heat Fuel Drier.

Powdered Coal Burners

There are a number of burners on the market which may be divided into two types, namely: the "stream line" and the "turbulent".

In the stream line, the coal and sufficient air to hold it in suspension, is forced into the furnace in a long stream, where it mixes with the air and is consumed. The burner is a round tube either with a round orifice or a fantailed orifice. Deflectors are frequently placed at the end of the tube to assist mixing of the fuel and air.

Fig. 34 shows a type of fuel feeder. The powdered coal feeds from the bin into a screw driven by a variable speed motor. The screw conveys the coal into a small mixing chamber containing paddles. Air at a pressure of six ounces is forced into the chamber, thoroughly mixing with the coal before it enters the burner.

Settings for Oil Burners (Extract from Helios)

The use of petroleum as fuel for steam generation has increased remarkably within the last decade. This has been brought about by the abundant supply resulting from the development of new oil fields, and by certain advantages of oil firing over coal firing. But as the supply of petroleum suitable for fuel has not kept pace with the unusual demand, uncertain deliveries and increasing cost are now working to the disadvantage of those plants using oil. There is no doubt but that oil ranks second in importance to coal as fuel for steam generation, but with the present rapid depletion of oil resources it is evident that oil firing will never supersede the use of coal.

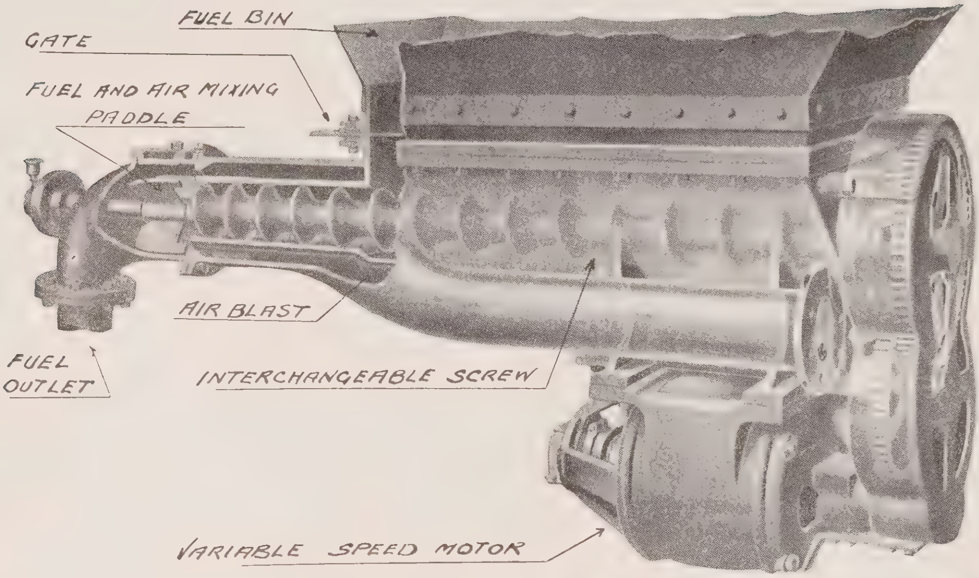

FIG. 34. Powdered Fuel Feeder.

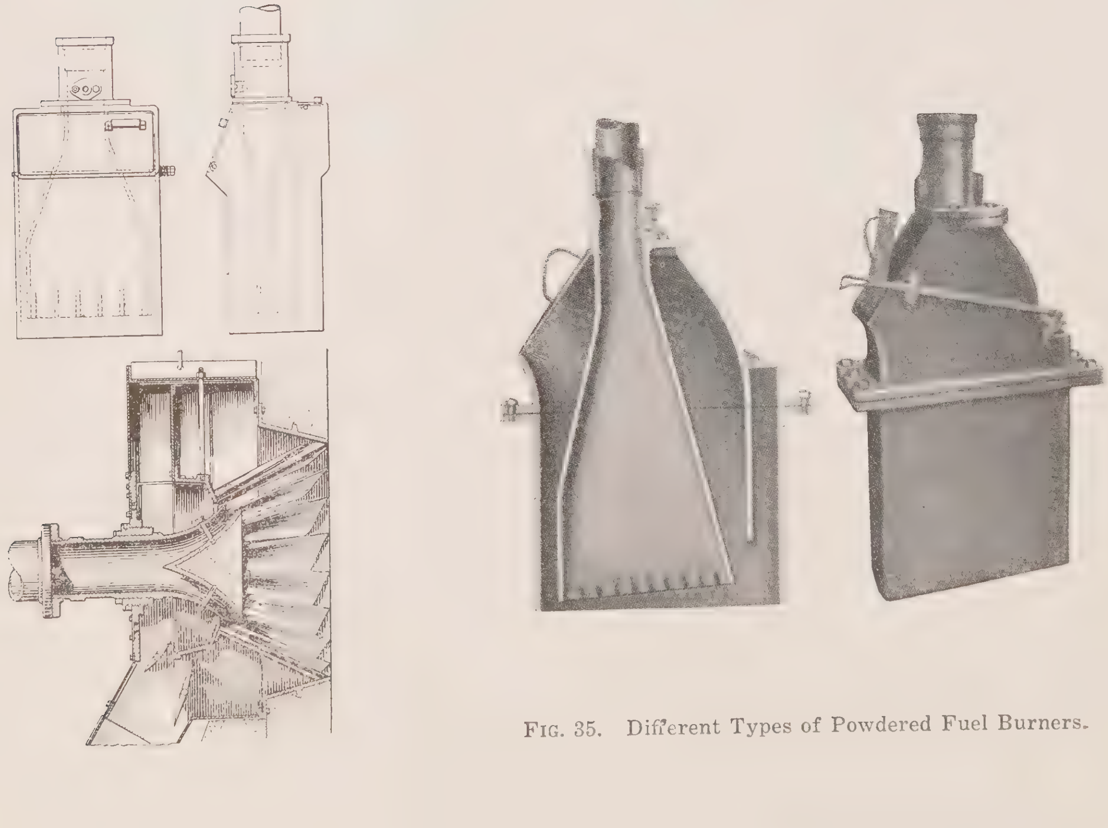

FIG. 35. Different Types of Powdered Fuel Burners.

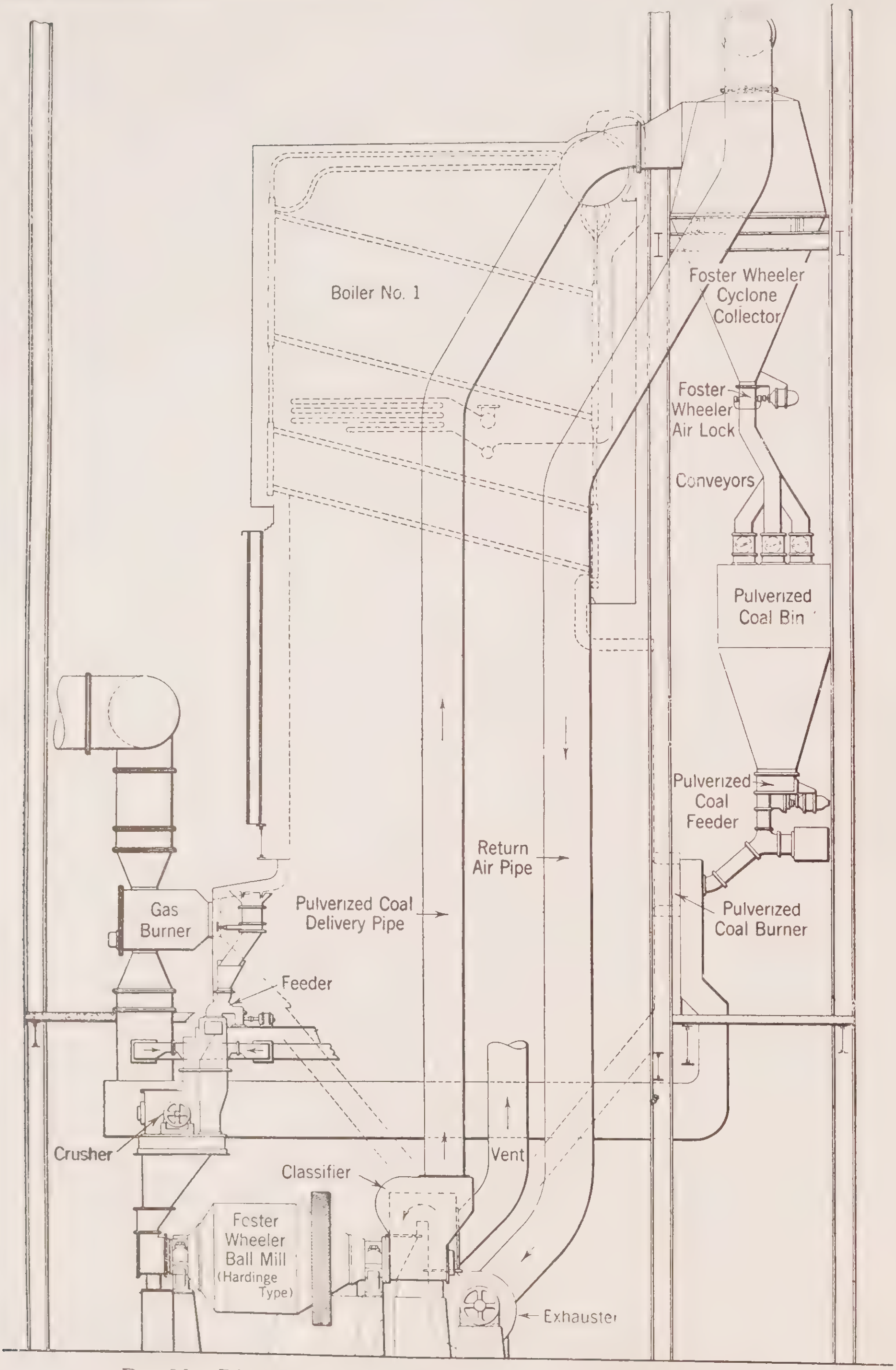

FIG. 36. Diagrammatic Illustration of a Powdered Fuel Plant.

In general the petroleum used for steam generation is of two types, the one commonly called fuel oil is the heavy oil resulting from a partial refining of paraffin crude, and the other is the unrefined, asphaltum-base, crude oil. The oils found in the mid-continent and Eastern fields contain a paraffin base, while those produced in the Gulf and Western fields contain an asphaltum base.

The success of oil firing depends largely upon proper furnace design, and there are a number of important points which must be considered. First, a large amount of refractory radiating surface must be provided to assist in combustion. Good practice in this regard is to allow from 0.9 to 1.2 square feet of radiating surface per boiler horsepower developed. Second, the furnace volume must be so proportioned that the gases are given time for complete combustion before reaching the comparatively cool heating surface. A combustion space of about two cubic feet per developed boiler horsepower will satisfactorily meet the average volumetric requirements.

The location of the burners in oil-fired setting design, should be such that the flame action will not be localized on portions of the heating surface, so that trouble from blow-torch action with the resultant blistering of tubes will be obviated. The oil or flame should not impinge directly on any portion of the furnace brickwork, because when starting up a furnace the oil dripping down after impingement on such cold surfaces may collect on the floor of the combustion chamber in such quantities that a serious explosion may occur when this pool of oil becomes heated up to the ignition point.

Oil Burners

One advantage in the use of oil for fuel lies largely in the fact that it can be broken up into minute drops so that the air for combustion comes into intimate contact with every particle of the liquid with the combustible gases evolved. The requirements for efficient combustion are a chamber of the proper proportions with the correct air supply properly distributed, and the thorough atomization of the entering fuel, the term "burner" being applied to the atomizing device. The desired effect is secured either by the action of steam or compressed air, which atomizes the oil and carries it into the furnace, or by purely mechanical means.

There are many types of oil burners and these are arranged differently because of the method of operation and the shape of the flame. Sometimes the oil is sprayed out in a fan-like flame between firebrick blocks, which form the approximate boundaries for the flame.

The burner can be inserted through the firing door, with the grates covered with checker-work with three-eighths inch space between the bricks, but the "low setting" is preferred, in which the grates are removed, and the checkerwork laid on supporting brick in the ashpit and the bridge wall cut level with the top of the checkerwork.

Steam atomizers include outside mixers, in which the steam impinges on the oil current just beyond the tip of the burner, and inside mixers in which the two come into contact within the burner. A combustible mixture of atomized liquid and volatile gases issues from the nozzle. In air atomizers, a jet of air under high or low pressure is used to break up the oil, part of the air for combustion entering in this manner. With mechanical atomizers

the oil, preferably heated, is forced out under pressure through a distributing tip, or by the whirling action of a revolving carrier.

Burners utilizing steam for atomization are installed in many stationary oil-burning power plants. They produce thorough atomization, with a long flame, but cannot be used where the steam would be liable to condensation, and great care must always be taken to keep the steam consumption down to a minimum. Air atomizers are desirable in marine work or in stationary plants where it is necessary to conserve the water supply, and they have the further advantage that the latent heat in the exhaust from the blowers or compressors is returned to the boiler, and no heat is carried away by the steam in the flue gases. They give a short, intense flame and the furnace brickwork must be proportioned accordingly. Under proper conditions, either steam or air atomizers can be operated with a steam consumption of two or three per cent. of that produced by the boilers. Mechanical atomizers require little steam and their exhaust can all be returned to the boilers. They are, in general, susceptible of very fine adjustment to meet varying load conditions.

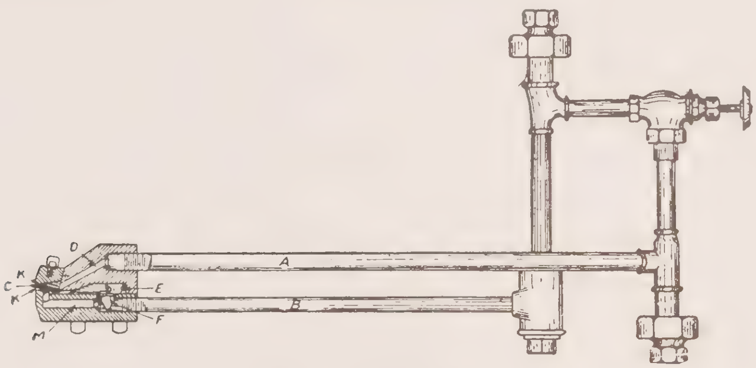

Fig. 37. An Oil Burner.

Figure 37 is one of several burners now on the market. It is an inside mixing burner in which the steam and oil come in contact within the burner. The oil enters at "a", flows through "d", into the mixing and atomizing chamber "c". The steam enters the mixing chamber through a pipe "b", passes through compartments "f" and "e" and then through small slots into the mixing chamber "c", where it meets the oil. These small jets cut across the oil stream at such angles that the energy of the steam is fully utilized. The heavy hydro-carbons are completely atomized. The light hydro-carbons are vaporized and the completed mixture issues from the burner and ignites like a strong gas flame.

Oil-Burning Plant Operation

In oil-burning plants it is usual for the fireman to be instructed to have the stack gas show a faint haze. This is not because such a haze denotes perfect or the best combustion. If the stack shows clear, it is impossible to know how much, if any, excess air is being used. A smoking stack is evidence of a lack of air, and by reducing the smoke to a mere haze the fireman knows that he has reduced the loss due to unburnt fuel to the lowest amount that can be indicated, although a clear stack might actually be giving a greater efficiency.

Economizers

As pointed out in a previous paragraph, the greatest loss in heat in a furnace is the amount of heat that passes up the smoke stack. Different apparatus has been devised to utilize a portion of this waste heat. One method is to place a feed water heater in the direct path of the flue gases before they enter the stack. This type of feed water heater is known as an economizer.

Figure 38 shows the installation of an economizer. Economizers are usually built separate from the boiler, although there are cases in which they are a part of the boiler. They are constructed of tubes through which the feed water passes on its way from the boiler feed pumps to the boiler. The flue gases must pass around the tubes on their way to the stack. Owing to the corrosive effect of the gases the tubes are usually made of cast iron, although where very high pressures are used, steel tubes must of necessity be used. A by-pass for the gases must be so arranged that the economizer can be cleaned and repaired without shutting down the boiler.

Large quantities of soot, which is contained in the gases, have a tendency to adhere to the tubes and if not removed, soon form a coating on the tubes that very materially affect the efficiency of the economizer and in time destroy its usefulness. To overcome this difficulty scrapers are made to move up and down the outside of the tubes, thus scraping off the soot, which falls to the bottom of the chamber from which it must be removed.

It can be readily seen that the relative value of the economizer depends on the temperature of the flue gas. If the boilers are being forced to such an extent that the flue gases have a temperature of, say, 600° F. or over, the economizer will increase the efficiency of the plant much more than when the gases are leaving the boiler at, say, 400°F. It is claimed the efficiency increase in using economizers may be anywhere from 5 to 20 per cent., depending on conditions.

With economizers, the feed water may be raised to a temperature of 75 or 80°F. higher

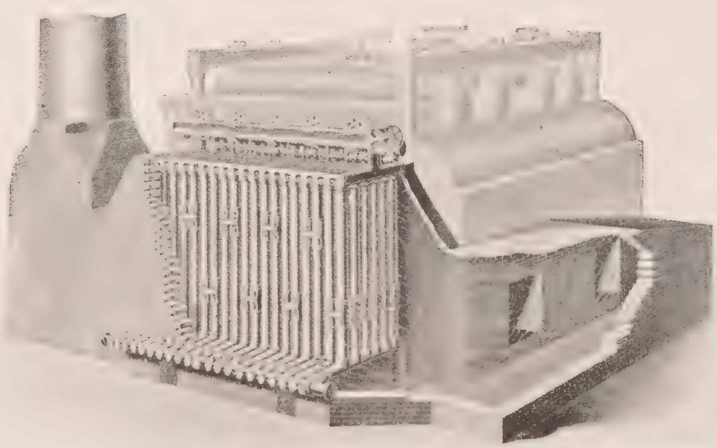

FIG. 38. Greene Economizer.

than in the ordinary feed water heater. This, of course, increases the capacity of the boiler to generate steam and furthermore, does not expose the boiler to such extremes of temperature.

The disadvantage of the economizer is its initial cost and rather expensive up-keep and the extra space it occupies.

An induced draft created by a fan is usually employed where economizers are installed.

Saving Effected by Economizers

Economizers are nothing more or less than feed water heaters. The purpose in both cases is to raise the temperature of the water entering the boiler. Economizers receive the heat from the flue gases while the feed water heaters receive their heat from the exhaust steam of engines, pumps, etc.

To calculate the saving effected by heating of the feed water we use the following formula:

$$\text{Per cent. saving} = \frac{(T - t)}{(H - t)} \times 100$$

in which T = heat units per pound of feed water above 32° F. after passing through the economizer or feed water heater.

t = heat units per pound of feed water above 32° F. before passing through the economizer or feed water heater.

H = heat units above 32° F. per pound of steam at boiler pressure.

For example, let us suppose the water enters the heater at 60°F. and leaves at a temperature of 180°F., and that the boiler gauge pressure is 150 pounds—what is the percentage gain by heating the water.

Substituting in the formula we have

$$\text{Per cent. saving} = \frac{(180 - 32) - (60 - 32)}{1195 - (60 - 32)} \times 100$$

$$= \frac{148 - 28}{1195 - 28} \times 100 = 10.29\%$$

Air Preheater

Of late years the air preheater has to a certain extent been superseding the economizer. Both are used to utilize the heat that would otherwise go to waste up the smoke stack. Considering the ordinary furnace, air entering the furnace at a temperature of around 60°F. and leaving at about 500°F. or more, it can be readily seen that there must be no small loss in heating this air, and that this loss will be proportionately reduced the nearer these two temperatures can be made equal. The reducing of the differences in temperature of the incoming and outgoing gases is the theory upon which the air preheater is based.

The air preheater is so arranged that all air supplied to the furnace must first pass through tubing or plating situated in the path of the outgoing gases, thereby absorbing a portion of the heat from the outgoing gases. In this way the incoming gases are heated and the outgoing gases cooled.

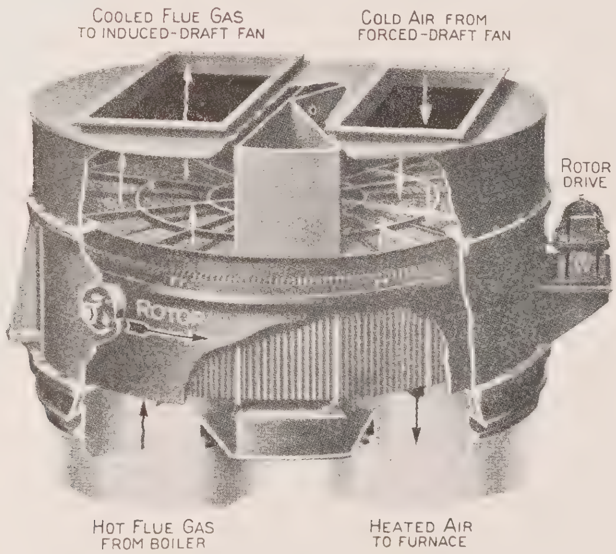

FIG. 39. Rotary Air Preheater.

Figure 39 shows a cut of one of the many different types of preheater. This is known as a rotating type. The rotary heat exchanger turns at a rate of from three to six revolutions per minute. The rotor is divided into two vertical compartments. Air is drawn down through one compartment and the hot flue gases are drawn up through the other compartment. The heat exchanger consists of alternating elements of thin corrugated steel and plain sheet steel, making a number of vertical passages for the downgoing air and for the upgoing gases to pass through.

While the gases are ascending in one compartment and heating it, the air is descending in the other compartment and absorbing the heat. As the rotor revolves, the compartments are alternately in the path of the hot gases and the air.

The gain from the preheater is not only in the absorbing of the waste heat from the

gases but also in the increased combustion on the grate, with less loss of coal through the grates. The preheater also makes combustion more complete without using much excess air.

The Howden forced draft system, Fig. 40, is very widely used in the merchant marine of this and other countries. It employs the closed ash-pit but provides for first preheating the air by flowing it over a nest of vertical tubes installed in the uptake. The waste gases pass through these tubes on their way to the funnel and the air flows around the tubes, recovering some of the lost heat and returning it to the furnace. Provision is made in this system for delivering a portion of the air over the fire. The Howden system differs from the ordinary closed ash-pit system chiefly in the two particulars of preheating the air and dividing the air delivery between the furnace and the ash-pit.

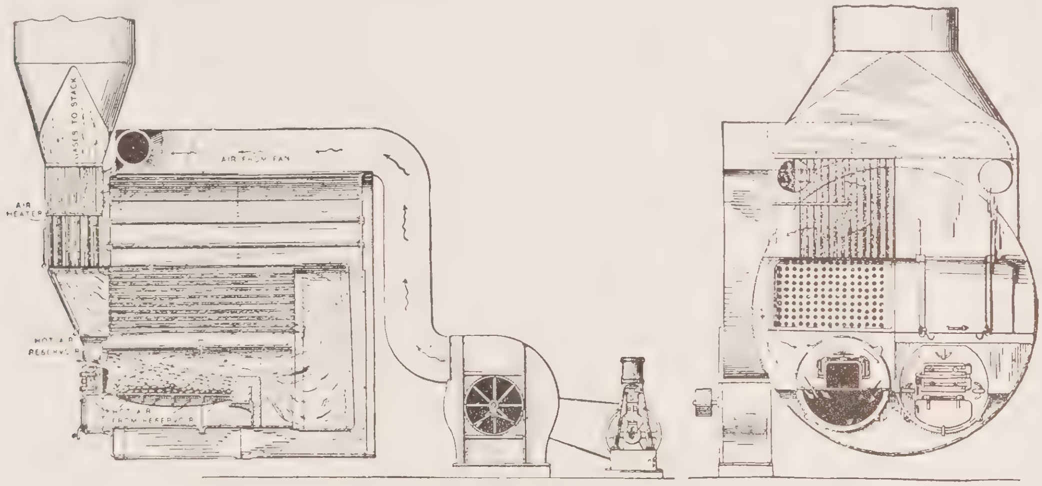

FIG. 40. Howden Forced Draft.

Air Preheated Effects (Cochrane Handbook)

Air heaters can be used in series with economizers, either before or after, but it is claimed that where they are used to replace economizers, a saving is effected in space, weight and cost, and that feed water is more advantageously heated by auxiliary exhaust or bled steam.

Jos. G. Worker lists the following effects of the application of preheated air to stoker operation:

1. The efficiency of the modern stoker and boiler and superheater at 200% boiler rating will be 83%.
2. The efficiency of the modern stoker, boiler, superheater and preheater at 200% boiler rating will be 90%.
3. The modern stoker can be operated to handle peaks of short duration up to 700% boiler rating.
4. The modern stoker can be operated at 500% boiler rating continuously.

5. The CO_2 performance with preheated air will range from 15½% at 250% boiler rating to 16½% at 350% rating and above.
6. Combustible loss in refuse will be less than 0.7 of 1% of B.T.U. in coal or 7% combustible in refuse.
7. 80,000 B.T.U. for maximum rating can be liberated per cubic foot of furnace volume per hour.
8. It is easier to burn coal which might otherwise smoke, entirely without smoke.
9. Elimination of continual cooling and heating of fine particles of ash by introduction of heated air in refuse, resulting in easier handling of refuse of fuel bed.
10. Preheated air in effect lengthens the stoker fuel bed by decreasing the amount of space required for drying the coal, making more effective the actual carbon burning zone.

Boiler Setting

The foundation for the boiler setting must be of sufficient strength to avoid settling and cracking of the walls.

The walls in small boilers are often required to support the weight of the boiler by means of lugs rivetted to the boiler shell and resting on the brickwork. Water tube boilers and large fire tube boilers are suspended from steel beams and in these cases the wall must support itself only.

The walls should be composed of well burned brick and the common practice is to make

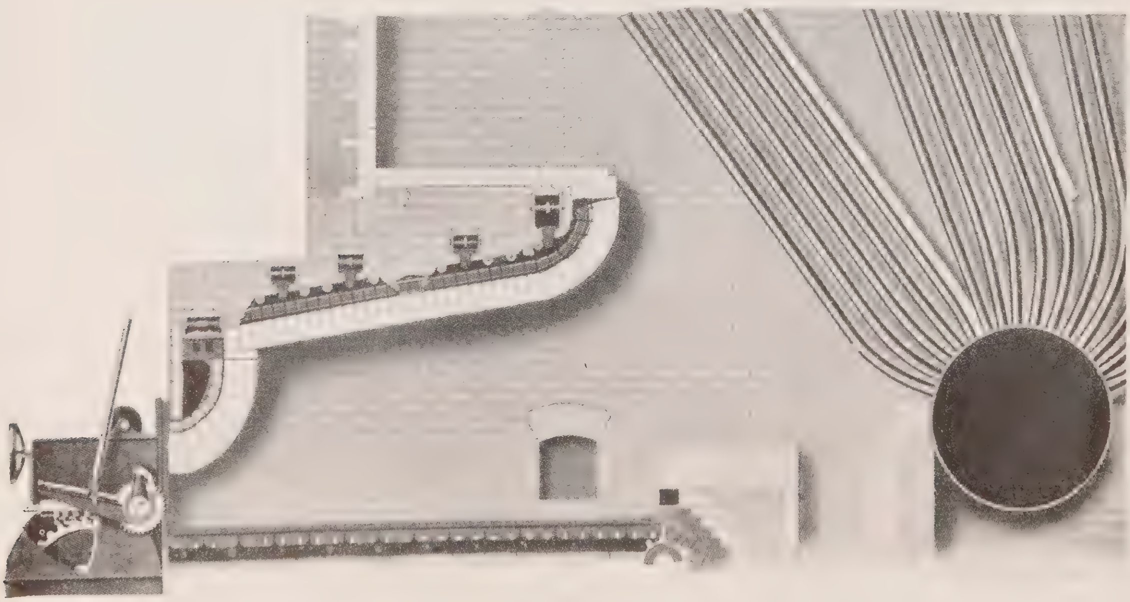

FIG. 41. Suspended Brick Arch.

them twelve inches thick. Wherever the brickwork is exposed to the intense heat of the fire the walls must be lined with firebrick.

Certain types of furnace such as the chain grate stokers require arches in the form of a roof over the fire. These arches are of the radial sprung type as shown in Fig 20, or the suspended type as shown in Fig. 41 and Fig. 42.

Firebrick (Extract from Helios)

The refractories used for linings, arches and bridge walls of boiler furnaces must withstand, without serious physical or chemical change, high and changing temperatures, action of flame and gases, and mechanical stresses due to the cleaning and adding of fuel to the fire. The refractories for boiler furnaces consist of bricks, blocks, or special forms, and paste. Fire clay (a mixture of silica and alumina) forms the basis of most refractory materials. According to F. T. Havard, fire clay is used either alone on account of its admirable qualities of burning to a firm clinker and resisting high temperatures and mechanical abrasion, or it is added to other refractory matter, such as bauxite and magnesia, to lend plasticity.

Fire clays are divided into two classes: flint clay and plastic clay, the former being the harder and more nearly chemically pure. Flint clays are white, gray or mottled black in colour. Plastic fire clays vary in colour from white to black, including gray, brown and olive. The plastic is added to the flint clay to increase the deformability, generally at the cost of its refractoriness. Commercial fire clay contains many impurities, and the colour is not a safe guide to its quality.

Plasticity, according to L. S. Marks, is considered the main factor in selection of fire brick. It indicates the tendency of a brick to become plastic at a temperature lower than its melting point and to become deformed under a given load. Under a unit stress of 100 lb. per sq. in., the plastic point should be more than 2400 deg., otherwise the brick is not suitable for boiler furnaces.

MELTING POINTS OF FIRE BRICK

Brick	Temp. Deg.
Fire Clay	2,732—3,182
Silica	3,092—3,182
Magnesia	3,902
Bauxite	2,912—3,272
Chromite	3,722

Many arches and walls seem to have failed because the mortar used in making the joints melts and allows the brick or blocks to fall. The mortar used should be of practically the same composition as the brick itself. For fire clay brick, finely ground fire clay mortar should be used; silica cement for silica brick; and magnesia cement for magnesia brick.

The fire clay mortar should be of the first quality, otherwise it will melt and run long before the brick. Common sand, salt, or lime, hasten fusion, and cement the brick thor-

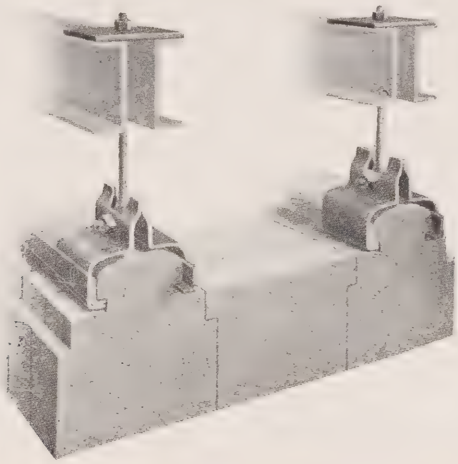

FIG. 42. Illustration showing of method of Suspending Brick Arch.

oughly, but at high temperatures this fusion destroys the brick prematurely. Tests by Raymond M. Howe show that the addition of only five per cent. of Portland cement, abestos or salt lowered the fusion point of fire clay almost 400 degrees. On the other hand, fire sand, which is calcined clay or fire brick in powder form, can be added to the mortar and prevents shrinkage of the raw clay and crumbling of the joints. This shrinkage can be prevented and a firmer joint established, not by adding foreign materials to the fire clay, but by using the same material, taking the precaution, however, that a certain amount of clay has previously been shrunk.

Bridge Wall

Behind the grates of the furnace in the H.R.T. boiler setting is placed the bridge wall. This wall is constructed of the same material and in the same manner as the furnace walls.

Care should be taken that clearance space is allowed at the end of the bridge wall to take care of expansion. If this is not attended to the expanding bricks will push outward and cause the side wall to crack.

It is claimed that the best results are obtained when the top of the bridge wall is flat and when about ten inches are allowed between the top of the wall and the boiler shell.

Combustion Chamber

Behind the bridge wall is a chamber known as the combustion chamber although the name is misleading. All combustion should take place before it reaches this chamber and there should be sufficient space over the grates for combustion to take place, a condition which unfortunately is not always present.

The true office of the combustion chamber is to check the velocity of the gases and allow the fine ash to separate before it reaches and is deposited on the tubes of the boiler.

Sometimes a sloping wall is built in the combustion chamber from the top of the bridge

wall, down to the back of the chamber, but experience has taught that this wall is of no benefit and therefore unnecessary. The combustion chamber is provided with clean out doors. It should be cleaned out at intervals so that no great quantity of ash will accumulate.

Baffles

All water tube boilers have baffles made of refractory brick placed between the tubes.

The purpose of baffles is to increase the travel of the gases, thus giving them the maximum exposure to the heating surface of the tube without interfering with the draft.

Baffles in some boilers are placed vertically, causing the gases to flow across the tubes, while in other boilers the baffles are placed horizontally, making the gases travel the length of the tubes.

The operating engineer should watch carefully that the baffling is in good condition and that there is no short circuiting of the gases to cause high stack temperatures and a reduction in boiler efficiency.

A differential draft gauge can be used to determine the drop in pressure between the different passes. If the reading points to a decrease in difference, it indicates that the baffling is always short circuiting.

Breeching

The connection from the boiler to the chimney is known as the breeching. The breeching should be as short and direct as possible. If possible, all turns should be avoided but if circumtances demand a turn it should be in the form of a long sweeping bend. Sharp turns increase friction and cause eddy currents. No angle irons should project inside the breeching as they cause eddy current.

Steel breeching is preferred to brick as it is tighter and less liable to develop leaks. It is preferable to have the breeching slope upward rather than downward toward the stack.

Breechings are supplied with clean-out doors and should be cleaned out frequently.

It is recommended that the area of the breeching be at least 20 per cent greater than the chimney area.

Chimneys

Chimneys are required for two purposes, (1), to carry off obnoxious gases; (2), to produce a draught and so facilitate combustion. The first requires size, the second height.

Each pound of coal burnt yields 13 or more pounds of gas, depending upon the excess of air with which combustion is completed, the volume of which varies with the temperature.

The weight of gas carried off by a chimney in a given time depends upon three things—size of chimney, velocity of flow, and density of gas. But as the density decreases directly as the absolute temperature, while the velocity increases, with a given height, nearly as the

square root of the temperature, it follows that there is a temperature at which the weight of gas delivered is a maximum. This is about 550° above the surrounding air. Temperature, however, makes so little difference that at 550° above, the quantity is only four per cent greater than at 300°. Therefore, height and area are the only elements necessary to consider in an ordinary chimney.

The intensity of draught depends upon the difference in weight of the outside and inside columns of air, which vary nearly as the product of the height into the difference of temperature. This is usually stated as an equivalent of a column of water, and may vary from 0 to possibly 2 inches.

The intensity of draught required varies with the kind of fuel and the thickness of the fires. Wood requires the least draught, and fine hard coal or slack the most. To burn anthracite slack to advantage a draught of 1¼ inch of water is necessary.

A round chimney is better than a square one and a straight chimney better than a tapering, though it may be either larger or smaller at top without much detriment.

The effective area of a chimney for a given power, varies inversely as the square root of the height. The actual area, in practice, should be greater, because of retardation of velocity due to friction against the walls.

Size of Chimneys (Kent)

The formula given below, and the table calculated therefrom for chimneys up to 96-in. diameter and 200 ft. high, were first published by the author in 1884 (Trans. A.S.M.E., vi, 81). They have met with much approval since that date by engineers who have used them, and have been frequently published in boiler-makers' catalogues and elsewhere. The table is now extended to cover chimneys up to 12 ft. diameter and 300 ft. high. The size corresponding to the given commercial horse-powers are believed to be ample for all cases in which the draught areas through the boiler-flues and connections are sufficient, say not less than 20% greater than the area of the chimney, and in which the draught between the boilers and chimney is not checked by long horizontal passages and right-angled bends.

Note that the figures in the table correspond to a coal consumption of 5 lbs. of coal per horse-power per hour. This liberal allowance is made to cover the contingences of poor coal being used, and of the boilers being driven beyond their rated capacity. In large plants, with economical boilers and engines, good fuel and other favourable conditions, which will reduce the maximum rate of coal consumption at any one time to less than 5 lbs. per H.P. per hour, the figures in the table may be multiplied by the ratio of 5 to the maximum expected coal consumption per H.P. per hour. Thus, with conditions which make the maximum coal consumption only 2.5 lbs. per hour, the chimney 300 ft. high x 12 ft. diameter should be sufficient for $6155 \times 2 = 12{,}310$ horse-power. The formula is based on the following data:

1. The draught power of the chimney varies as the square root of the height.
2. The retarding of the ascending gases by friction may be considered as equivalent to a diminution of the area of the chimney, or to a lining of the chimney by a layer of gas which has no velocity. The thickness of this lining is assumed to be 2 inches

for all chimneys, or the diminution of area equal to the perimeter $\times$ 2 inches (neglecting the overlapping of the corners of the lining). Let D = diameter in feet, A = area, and E = effective area in square feet:

For square chimneys, $E = D^2 - \frac{8D}{12} = A - \frac{2}{3}\sqrt{A}.$

For found chimneys, $E = \frac{\pi}{4}(D^2 - \frac{8D}{12}) = A = 0.591\sqrt{A}.$

For simplifying calculations, the coefficent of $\sqrt{A}$ may be taken as 0.6 for both square and round chimneys, and the formula becomes:

$$E = A - 0.6\sqrt{A}.$$

3. The power varies directly as this effective area E.

4. A chimney should be proportioned so as to be capable of giving sufficient draught to cause the boiler to develop much more than its rated power, in case of emergencies, or to cause the combustion of 5 lbs. of fuel per rated horse-power of boiler per hour.

5. The power of the chimney varying directly as the effective area, E, and as the square root of the height, H, the formula for horse-power of boiler for a given size of chimney will take the form

$$H.P. = CE\sqrt{H}, \text{ in which C is a constant,}$$

the average value of which, obtained by plotting the results obtained from numerous examples in practice, the author finds to be 3.33.

The formula for horse-power then is:

$H.P. = 3.33\,E\sqrt{H}$, or $H.P. = 3.33\,(A - 0.6\sqrt{A})\sqrt{H}.$

If the horse-power of boiler is given, to find the size of chimney, the height being assumed,

$$E = 0.3\,H.P. \div \sqrt{H}; = A - 0.6\sqrt{A}.$$

For round chimneys, diameter of chimney = diameter of $E + 4''$.

For square chimneys, side of chimney = $\sqrt{E} + 4''$.

If effective area E is taken in square feet, the diameter in inches is

$$d = 13.54\sqrt{E} + 4'',$$

and the side of a square chimney in inches is

$$s = 12\sqrt{E} + 4''.$$

If horse-power is given and area assumed, the height

$$H = \left(\frac{0.3\,H.P.}{E}\right)^2$$

An approximate formula for chimneys above 1000 H.P. is

$$H.P. = 2.5\ D\ \sqrt{H}.$$

This gives the H.P. somewhat greater than the figures in the table.

In proportioning chimneys the height should first be assumed, with due consideration of the heights of surrounding buildings or hills near to the proposed chimney, the length of horizontal flues, the character of coal to be used, etc.; then the diameter required for the assumed height and horse-power is calculated by the formula or taken from the table.

SIZE OF CHIMNEYS FOR STEAM-BOILERS

Formula, $H.P. = 3.33\ (A - 0.6\ \sqrt{A})\ \sqrt{H}$. (Assuming 1 h.p. = 5 lbs. of coal burned per hour.)

Diam. inches	Area A sq. ft.	Effective Area $E = A - 0.6\sqrt{A}$ sq. ft.	Height of Chimney									Equivalent Square Chimney Side of Square $\sqrt{E} + 4$ ins.
			50 ft.	70 ft.	90 ft.	110 ft.	125 ft.	150 ft.	200 ft.	250 ft.	300 ft.	
			Commercial Horse-power of Boiler									
18	1.77	0.97	23	27	......	......	......	......	......	......	......	16
21	2.41	1.47	35	41	......	......	......	......	......	......	......	19
24	3.14	2.08	49	58	66	......	......	......	......	......	......	22
27	3.98	2.78	65	78	88	......	......	......	......	......	......	24
30	4.91	3.58	84	100	113	......	......	......	......	......	......	27
33	5.94	4.48	......	125	141	156	......	......	......	......	......	30
36	7.07	5.47	......	152	173	191	204	......	......	......	......	32
39	8.30	6.57	......	183	208	229	245	268	......	......	......	35
42	9.62	7.76	......	216	245	271	289	316	......	......	......	38
48	12.57	10.44	......	......	330	365	389	426	492	......	......	43
54	15.90	13.51	......	......	427	472	503	551	636	......	......	48
60	19.64	16.98	......	......	536	593	632	692	800	894	......	54
66	23.76	20.83	......	......	......	728	776	849	981	1097	1201	59
72	28.27	25.08	......	......	......	876	934	1023	1181	1320	1447	64
78	33.18	29.73	......	......	......	1038	1107	1212	1400	1565	1715	70
84	38.48	34.76	......	......	......	1214	1294	1418	1637	1830	2005	75
90	44.18	40.19	......	......	......	......	1496	1639	1893	2116	2318	80
96	50.27	46.01	......	......	......	......	1712	1876	2167	2423	2654	86
102	56.75	52.23	......	......	......	......	1944	2130	2459	2750	3012	91
108	63.62	58.83	......	......	......	......	2090	2399	2771	3098	3393	96
114	70.88	65.83	......	......	......	......	......	2685	3100	3466	3797	101
120	78.54	73.22	......	......	......	......	......	2986	3448	3855	4223	107
132	95.03	89.18	......	......	......	......	......	3637	4200	4696	5114	117
144	113.10	106.72	......	......	......	......	......	4352	5026	5618	6155	128

For pounds of coal burned per hour for any given size of chimney, multiply the figures in the table by 5.

Chimneys with Forced Draught

When natural, or chimney, draught only is used, the function of the chimney is (1), to produce such a difference of pressure, or intensity of draught, between the bottom of the chimney and the ash-pit as will cause the flow of the required quantity of air through the grate-bars and the fuel bed, and the flow of the gases of combustion through the gas passages, the damper and the breeching; and (2), to convey the gases above the tops of surrounding buildings and to such a height that they will not become a nuisance. With forced

draught the blower produces the difference of pressure, and the only use of the chimney is that of conveying the gases to a place where they will cause no inconvenience; and in that case the height of the chimney may be much less than that of a chimney for natural draught.

With oil or natural gas for fuel, the resistance of the grates and of the fuel bed is eliminated, and the height of the chimney may be much less than that of one desired for coal firing. When oil or gas is substituted for coal, and the chimney is a high one, it may be necessary to restrict its draught power by a damper or other means, in order to prevent its creating too great a negative pressure in the furnace and thereby too great an admission of air, which will cause a decrease in efficiency.

Velocity of Gas in Chimneys

The velocity of the heated gas, based on the chimney proportons, may be found from the following data:

A = Lb. coal per hour = boiler horse-power $\times$ 5;

B = Lb. gas per lb. coal = say 20 lb.

C = Cu. ft. of gas per lb. of gas = 12.4 $\times$ (temp. of gas + 460) $\div$ 492 = 25 cu. ft. for 532°F. = 500 cu. ft. per lb. coal;

V = Velocity of gas, feet per second =

$$\frac{A \times B \times C}{\text{Chimney area (sq. ft.)} \times 3600'}$$

Based on a gas temperature of 532°F., 5 lb. coal per hour per rated H.P., and 20 lb. gas per lb. of coal we have

Cu. ft. gas per second per lb. of coal per hour = 0.1389;
Cu. ft. gas per second per boiler horse-power = 0.6944;

and the velocities in feet per second, based on the effective areas given in the table, corresponding to different heights of chimney are:

Height, ft.	50	60	70	80	90	100	110	125	150	175	200	225	250	300
Velocity, ft. per sec.	16.3	17.8	19.4	20.7	22.0	23.2	24.3	25.9	28.3	30.6	32.7	34.7	36.6	40.1

Heights of Chimney Required for Different Fuels

The minimum height necessary varies with the fuel, wood requiring the least, then good bituminous coal, and fine sizes of anthracite the greatest. It also varies with the character of the boiler—the smaller and more circuitous the gas-passages the higher the stack required; also with the number of boilers, a single boiler requiring less height than several that discharge into a horizontal flue. No general rule can be given.

C. L. Hubbard says: The following heights have been found to give good results in

plants of moderate size, and to produce sufficient draught to force the boilers from 20 to 30 per cent above their rating:

With free-burning bituminous coal, 75 feet; with anthracite of medium and large size, 100 feet; with slow-burning bituminous coal, 120 feet; with anthracite pea coal, 130 feet; with anthracite buckwheat coal, 150 feet. For plants of 700 or 800 horse-power and over, the chimney should not be less than 150 feet high regardless of the kind of coal to be used.

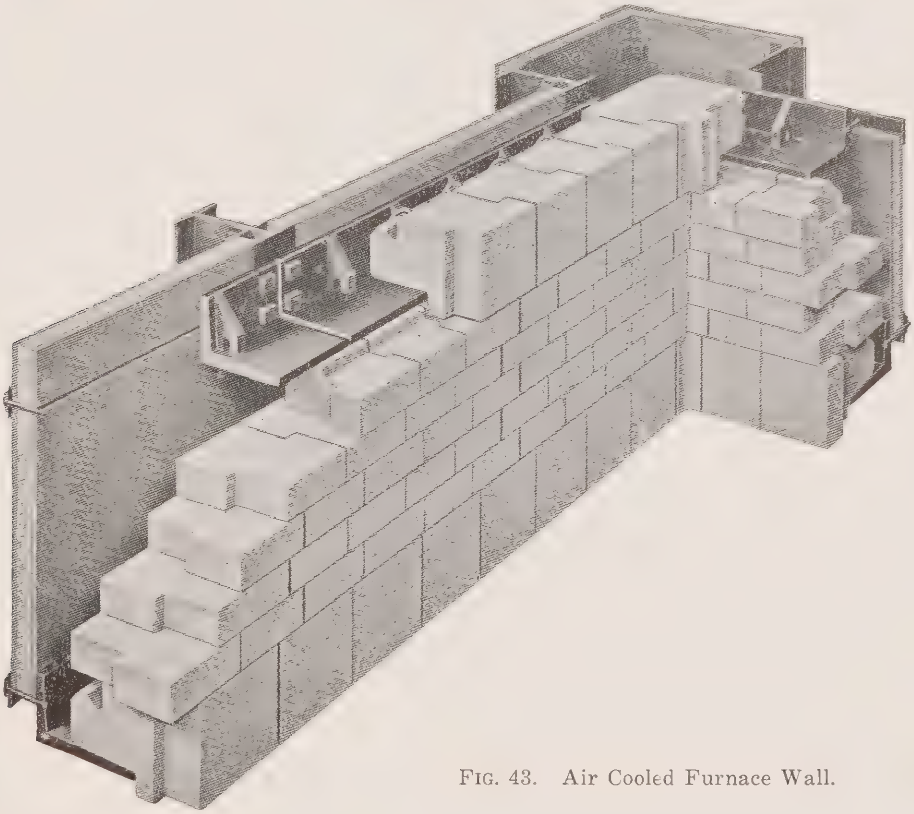

FIG. 43. Air Cooled Furnace Wall.

Air Cooled Furnace Walls

In a preceding paragraph we have explained that all furnace walls must be lined with fire brick because ordinary brick cannot withstand the intense heat.

In the modern large power plant using either stokers or pulverized fuel with preheated air, and forced to a very high rating, even the firebrick cannot withstand the high furnace temperatures.

To overcome this difficulty air cooled walls are sometimes used. The air must pass through the duct within the two sections of the wall on its way to the furnace. Sometimes the inner lining of the lower parts of the side walls and bridge wall are built of perforated refractory blocks. The fan driven air passes through the holes from the air ducts. The idea is to reduce the temperature of the bricks and prevent clinkers from clinging to them.

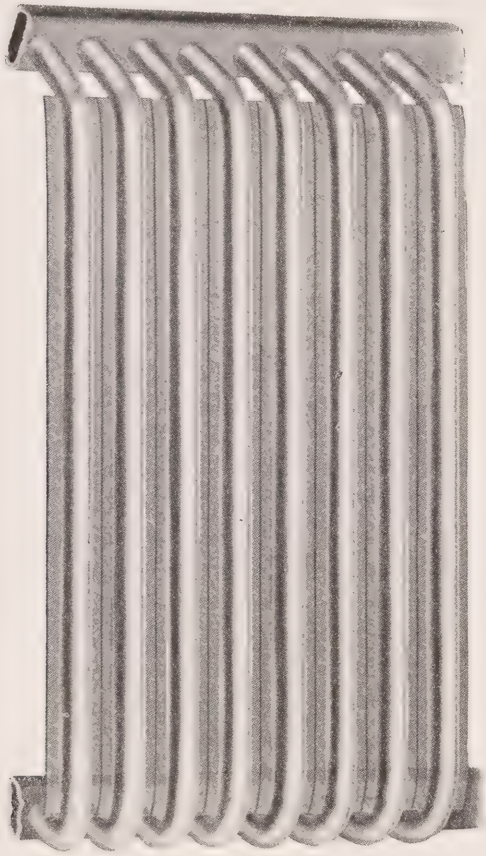

FIG. 44. Water Cooled Furnace Wall.

Water Cooled Furnace Walls

Another method of overcoming this difficulty and furthermore, of adding to the heating surface of the boiler, is the development of water cooled furnaces. The inner lining of these furnace walls consists of a series of especially designed water tubes. These tubes have projections known as fins, welded on two sides, so that when the tubes are put in place they offer a complete metal surface to the fire (see Fig. 44 and Fig. 45).

The water in the fin tubes is part of the boiler circulation extending from the boiler drum, through the downtake tubes to the lower header, up through the fin tubes to the upper header and on to the steam drum by way of the uptake tubes. The steam which is generated in the tubes is collected in the upper header and delivered to the main boiler drum.

These fin walls are also used in the front wall of the furnace as superheaters, but the extent that they can be used for this purpose is limited to the amount of superheat that can be utilized.

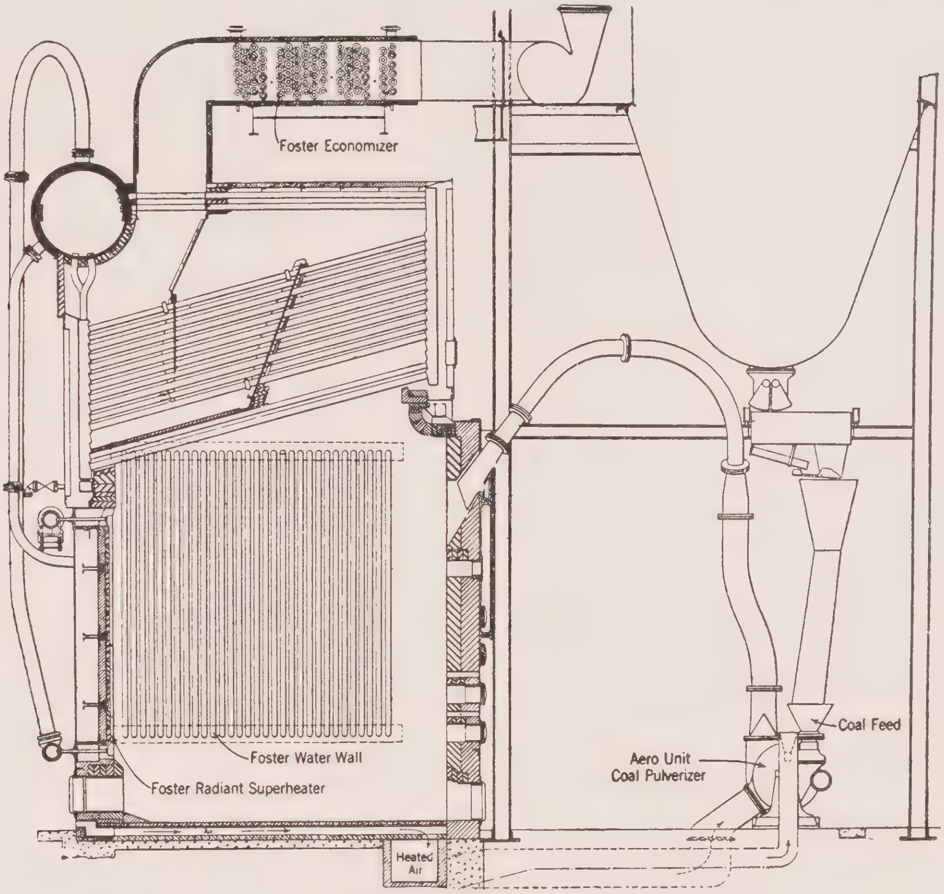

FIG. 45. Sectional view showing position of water walls.

Pyrometers

As mercury boils at 680 degrees Fahrenheit it cannot be used in the ordinary thermometer to measure temperatures above this point. In fact, it should not be used above 500 unless it is a special type. When the space above the mercury is filled with compressed nitrogen and specially hard glass is used for the tube, mercury thermometers may be used to indicate temperatures as high as 1,000 degrees. This type of thermometer is very convenient for measuring stack temperatures.

The operating engineer is well advised to keep a record of the stack temperature. If the temperature is rising from day to day it indicates that something is wrong. Perhaps the baffling has broken down allowing the gases to by-pass, or soot is gathering thickly on the heating surface of the boiler. On the other hand, if the temperature is dropping, it may indicate a better method of firing or it may be due to leakage in the setting and around the breeching allowing sufficient cold air to enter to reduce the stack temperature. Perhaps both broken baffles and air leaks exist, in which case the thermometer indicates nothing

unusual. A very rough estimation of the temperature of the fire may be made by observing its colour. The following table is given as a guide in estimating the temperature. A pyrometer based on the principle of colour has been designed but it is rather too delicate an instrument to be used freely in the boiler room.

Character of Light	*Temperature ° F.*
Dark red, blood red, low red	1050
Dark cherry red	1175
Cherry red	1375
Bright cherry, light red	1550
Orange	1650
Light orange	1725
Yellow	1825
Light yellow	1975
White	2200

There have been many different types of pyrometers for measuring high temperatures, some of which are as follows:

Electrical Resistance Thermometers are based on the variation of the electrical resistance of certain metals with the temperature. Platinum has a uniform resistance and withstands high temperatures, hence is often used for this work. The resistance thermometer is made of a coil of pure annealed platinum wire wound upon a mica framework. The variation in resistance is measured by a Wheatstone bridge. Inasmuch as small currents are used with this device, delicate galvanometers are required.

Thermo-electric Pyrometers are based upon the fact that when wires of two different metals are joined at one end and heated, an electro-motive force will be set up between the free end or cold ends of the wires. The combination of two such wires is known as a thermo-couple. The voltage so set up, when the "hot" end is at a higher temperature than the "cold" end, usually increases as the temperature difference increases and may be measured by a sensitive galvanometer or voltmeter.

There are two general types of thermo-couples, namely: high resistance and low resistance. The high resistance couple is formed of platinum and platinum-rhodium wires of small diameter and is often called a rare metal couple. Base metal or low resistance couples are made of iron versus sonstantan, chromel versus alumel and various other special patented alloys that are obtainable in sizes of No. 6 or 8 B.W.G. Platinum and platinum-rhodium couples may be used up to a temperature of 3500°F., though their safe working temperature depends on the character of the alloys used.

Thermo-couples, whether of the rare metals or base metal types, should preferably be housed in protecting tubes. Iron pipe will satisfactorily serve as a protecting tube up to 1500°F. but above this temperature, special alloy, quartz or porcelain tubes should be used.